THE RELATION OF EXERCISE TRAINING MODE, BRAIN OXYGENATION AND COGNITION IN HEALTHY OLDER ADULTS

by

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Dissertation presented for the Degree of Doctor of Sport Science in the Faculty of Education at Stellenbosch University

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Faculty of Education

December 2015

Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

This dissertation includes one original paper published in a peer-reviewed journal and two unpublished publications. The development and writing of the papers (published and unpublished) were the principal responsibility of myself and, for each of the cases where this is not the case, a declaration is included in the dissertation indicating the nature and extent of the contributions of co-authors.

December 2015

Summary

Background: Physical exercise has been shown to prevent cognitive decline and dementia in later life and is generally proposed as a non-pharmacological treatment to reverse or delay the age-related deteriorations in physical and cognitive health. However, it is unknown how different types of exercise will compare with regards to gains in older individuals' physical and cognitive function and, in particular, the role of high-intensity interval training, has not been extended to the cognitive function literature.

Aims: The purpose of this thesis was to determine the effects of three different exercise training modalities (resistance training, high-intensity interval training and moderate continuous training) on physical and cognitive function, as well as cerebral oxygenation.

Methods: Sixty seven inactive individuals (55 to 75 years) volunteered for this intervention study. Participants were allocated to a resistance training (RT) group (n=22), high-intensity interval training (HIIT) group (n=13), moderate continuous training (MCT) group (n=13) and a control (CON) group (n=19). Each training group performed three supervised exercise sessions per week over a period of 16 weeks. Cognitive function was assessed every four weeks with a computerized Stroop task, while physical function was assessed with the Timed-Up-and-Go (TUG) and submaximal Bruce treadmill tests. Changes in cerebral oxygenation during the Stroop task were measured at baseline and after the 16-week intervention period. Furthermore, muscle strength was assessed in the CON and RT groups with 10RM leg and bench press tests. The RT and CON groups repeated their baseline measurements after a subsequent 16-week detraining (DET) period.

Results: Upper and lower body strength generally improved significantly after every four weeks of RT (with an increase after 16 weeks of 7.3 ± 4.9 kg and 86.6 ± 44.4 kg, respectively; $P < 0.001$), while TUG performance (-0.2 ± 0.4 s; $P < 0.05$) and submaximal endurance capacity (0.7 ± 0.9 min; $P < 0.001$) only improved after 16 weeks. Although muscle strength decreased after detraining, it remained at a level higher than baseline ($P < 0.05$). Submaximal endurance capacity improved after DET ($P < 0.001$), while TUG performance returned to baseline. The HIIT group showed a greater improvement in TUG performance (-0.3 ± 0.4 s; ES = 0.36) and walking endurance (1.4 ± 1.3 min; ES = 0.91) compared to RT and MCT. Within each group only RT showed statistically significant improvements, with HIIT and MCT presenting the same trend, beyond the 4-week intervention period, on the measures of executive cognitive function (ES > 0.70). The brain oxygenation results revealed higher relative O_2Hb values in CON during the simple and complex Stroop tasks at the post-test compared to the pre-test values ($P < 0.05$), as well as compared to all three exercise training groups ($P < 0.05$).

Conclusion: Increases in muscular and physical function in older individuals were not induced in a concurrent manner over the course of a RT programme. Furthermore, older adults retained a significant amount of muscle strength and submaximal endurance capacity after a period of DET, while functional mobility was completely reversed. HIIT proved to be most beneficial for the enhancement of older individuals' aerobic fitness. Exercise training proved more beneficial for the enhancement of executive cognitive function compared to no training. It was also demonstrated that exercise training, independent of the mode, results in more efficient cerebral oxygenation during cortical activation, whereas HIIT and MCT proved to be superior to RT for task-efficient cerebral oxygenation and improved oxygen utilization during cortical activation in older individuals.

Opsomming

Agtergrond: Fisieke inoefening word voorgestel as 'n nie-farmakologiese behandeling om die ouderdomsverwante agteruitgang in fisieke en kognitiewe gesondheid teen te werk of te vertraag. Nietemin is dit onbekend hoe verskillende oefeningsmodaliteite met mekaar vergelyk in terme van die voordelige effek op ouer individue se fisieke en kognitiewe funksie. Die invloed van hoë-intensiteit interval inoefening op hierdie uitkomstes is nog nie ondersoek nie.

Doel: Die doel van hierdie studie was om die effek van verskillende oefeningsmodaliteite (weerstands inoefening, hoë-intensiteit interval inoefening, en matige kontinue inoefening) op fisieke funksie, kognitiewe funksie en serebrale oksigenasie in 'n ouer populasie te ondersoek.

Metodes: Sewe-en-sestig onaktiewe individue (55 tot 75 jaar) het ingestem om aan die intervensie studie deel te neem. Deelnemers is aan die weerstands inoefening (RT) groep (n=22), hoë-intensiteit interval inoefening (HIIT) groep (n=13), matige kontinue inoefening (MCT) groep (n=13) en kontrole (CON) groep (n=19) toegeken. Drie oefensessies per week is onder toesig uitgevoer. Kognitiewe funksie is elke vier weke geevalueer deur middel van 'n gerekenariseerde Stroop taak, terwyl fisieke funksie deur 'n "Timed-Up-and-Go" (TUG) en submaksimale Bruce trapmeul toets geassesseer is. Veranderinge in serebrale oksigenasie gedurende die Stroop taak is tydens basislyn en na afloop van die intervensie periode gemeet. Die CON en RT groepe se spierkrag is deur middel van 'n 10RM been- en armopstoot toets geëvalueer. Die RT en CON groepe het weer die basislyntoetse na 'n addisionele 16 weke van onaktiwiteit (DET) uitgevoer.

Resultate: Bo- en onderlyfkrag het oor die algemeen beduidend verbeter na elke vier weke in RT (met 'n algehele toename van 7.3 ± 4.9 kg en 86.6 ± 44.4 kg, onderskeidelik; $P < 0.001$),

terwyl TUG prestasie (-0.2 ± 0.4 s; $P < 0.05$) en submaksimale uithouvermoë kapasiteit (0.7 ± 0.9 min; $P < 0.001$) slegs na 16 weke verbeter het. Alhoewel ‘n afname in spierkrag plaasgevind het gedurende die periode van onaktiwiteit (DET), was dit steeds hoër as by die basislynmetings ($P < 0.05$). Submaksimale uithouvermoë kapasiteit het verbeter na DET ($P < 0.001$), terwyl TUG terugekeer het na basislyn. Die HIIT groep het ‘n groter toename in TUG prestasie (-0.3 ± 0.4 s; ES = 0.36) en stap uithouvermoë (1.4 ± 1.3 min; ES = 0.91) na die 16-week oefenprogram getoon. Geen beduidende veranderinge is in die MCT en CON groepe gevind nie ($P > 0.05$).

Slegs RT het ‘n statisties beduidende verbetering in uitvoerende kognitiewe funksie vanaf die 4-16 week intervensie periode getoon, met HIIT en MCT wat ‘n soortgelyke tendens gevolg het (ES > 0.70). Die breinoksigenasie resultate na die intervensie het ‘n beduidende toename in CON se relatiewe oksihemoglobien (O_2Hb) tydens die eenvoudige en ingewikkelde Stroop take getoon ($P < 0.05$). Hierdie verhoogde vlakke van O_2Hb was ook beduidend hoër in vergelyking met die drie oefengroepe se post-toets waardes gedurende albei Stroop takies ($P < 0.05$).

Gevolgtrekking: Die toename in spierkrag en fisieke funksie in ouer volwassenes het nie ‘n soortgelyke patroon gevolg oor die verloop van die 16 weke nie. Na DET is ‘n beduidende hoeveelheid spierkrag en submaksimale uithouvermoë kapasiteit behou, terwyl die funksionele mobiliteit teruggekeer het na basislyn. Daar is ook bevind dat HIIT meer voordelig is vir die verbetering van aërobiese fiksheid. Die resultate wys dat inoefening (teenoor onaktiwiteit) tot verhoogde uitvoerende kognitiewe funksie lei. Die huidige studie toon ook dat fisieke oefening meer effektiewe serebrale oksigenasie tydens kortikale aktivering induseer. HIIT en MCT was meer effektief as RT vir taak-effektiewe serebrale oksigenasie en verbeterde suurstofverbruik tydens kortikale aktivering in ouer individue.

Acknowledgements

There are a number of people who undoubtedly deserve a medal for their unique contribution to this study:

I am very grateful for the courage and strength instilled in me by our mighty Lord. Having the opportunity to go through such an incredible learning experience is nothing but a blessing.

Prof. Elmarie Terblanche, thank you for all your patience and guidance throughout this PhD project. Your incredible work ethic continues to inspire me and it was such an honour working with you. I appreciate all the time and effort that you put into this thesis and you are the reason why I feel very proud of this accomplishment.

My father, sister and friends, I deeply appreciate all your support and words of encouragement.

Lara Grobler, my friend and fellow researcher, you have helped me in so many ways over the last three years. Thank you for all your advice and guidance, and your positive attitude. You and Louise Engelbrecht made this experience truly enjoyable. I thank you!

My colleagues at the Stellenbosch Biokinetics Centre, Elbé de Villiers and Ian Rainsford, thank you for your support and continued motivation. Thank you, Elbé, for allowing me to use the Centre facilities for my research project, along with the help of the Biokinetics Honours students.

I would like to express a special word of gratitude towards my study participants. Without you this research project would not have been possible.

I am very grateful for the assistance of Prof. Martin Kidd with all the statistical analyses.

Finally, the financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. It should be noted that opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

Parts of this thesis have been presented at two International conferences in 2014, namely the 19th Annual Congress of the European College of Sport Science held in Amsterdam and the Life Through Movement International Conference held at Stellenbosch University.

List of abbreviations and acronyms

Δ	-	Delta (Change of)
μMol	-	Micromol
ACSM	-	American College of Sports Medicine
BL	-	Baseline
BMI	-	Body mass index
CON	-	Control
DET	-	Detraining
ECG	-	Electrocardiograph
EMG	-	Electromyogram
ES	-	Effect size
Hb	-	Haemoglobin
HHb	-	Deoxy-haemoglobin
HIIT	-	High-intensity interval training
HR_{max}	-	Maximal heart rate
HRR	-	Heart rate reserve
LPFC	-	Left prefrontal cortex
MCT	-	Moderate continuous training

MoCA	-	Montreal Cognitive Assessment
MRI	-	Magnetic resonance imaging
NIR	-	Near-infrared
NIRS	-	Near-infrared spectroscopy
O_2Hb	-	Oxy-haemoglobin
P	-	Probability
r	-	Correlation coefficient
RM	-	Repetition maximum
RPE	-	Rating of perceived exertion
RT	-	Resistance training
SD	-	Standard deviation
THI	-	Total haemoglobin index
THR	-	Target heart rate
TUG	-	Timed-Up-and-Go
VO_{2max}	-	Maximal oxygen uptake
VO_{2peak}	-	Peak oxygen uptake

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All parts of the body which have a function, if used in moderation and exercised in labours in which each is accustomed, become thereby healthy, well developed and age more slowly, but if unused they become liable to disease, defective in growth and age quickly.

— *Hippocrates*

Chapter 1: Problem statement

A. The effect of age on physical and cognitive function

The ageing process in human beings is associated with a decline in physical and cognitive health (23, 32). Aerobic fitness (13), muscle strength (16), functional mobility (5) and executive cognitive control (27) are merely some of the affected functions. As a result, ageing individuals experience deteriorations in their wellbeing and levels of functionality.

B. The effect of exercise training on physical and cognitive function

Physical exercise is considered a non-pharmacological treatment to reverse age-related deteriorations and preserve an adequate level of physical function. The positive effect of exercise on physical and mental health is a well-known fact. Regular exercise is associated with a decreased risk of cardiovascular and metabolic diseases (35), a lower prevalence of osteoporosis (18), a reduction in frailty (22) and an improved lifestyle and mental wellbeing (14, 17, 26). This beneficial effect of exercise on cognition is of utmost importance, especially during old age. Exercise has been shown to prevent cognitive decline and dementia in later life (21). Improved cognition will not only aid in the enhancement of health and wellbeing, but it will also promote independent living. As a result, there will be a lessened burden on the public health sector and the national economy.

1. Exercise training and endurance capacity

While aerobic training interventions report greater increases in cardiorespiratory fitness compared to resistance training (10, 36), high intensity interval training (HIIT) induces even better cardiorespiratory benefits when compared with traditional endurance training (39). Whereas HIIT was once only a training method for athletes, it is now also successfully applied in other healthy and diseased populations. The literature reports favourable effects of HIIT on central and peripheral adaptations which are associated with improved health outcomes in many clinical populations (15, 39).

The majority of researchers investigated the effects of HIIT on cardiovascular function, metabolic adaptations, body composition and underlying health markers, i.e. glucose and cholesterol levels in younger individuals (19, 30, 37, 38, 40), whereas HIIT interventions in the older population focus predominantly on cardiac rehabilitation (28, 29, 41). It remains to be seen if this training mode has any significant effect on cognitive health in older individuals.

2. Exercise training and cognitive function

Aerobic and resistance exercise have been reported to enhance older individuals' cognitive function (2, 4, 6, 10, 24, 25). The literature suggests that acute exercise of a moderate intensity, independent of mode, has the most significant influence on aspects of executive cognitive control (1, 7, 8, 20). It is also believed that chronic aerobic and resistance training have a selective effect on cognitive function, with the largest benefits observed for tasks requiring greater executive control (2, 6, 9).

Since cardiovascular fitness was suggested to play a mediating role in older adults' cognitive function (33), the question remains whether HIIT, with its superior effects on aerobic fitness, even in older adults, will also enhance cognitive function to a greater extent.

C. Cognitive function and performance

1. The Stroop task – a test of cognitive function

Tests designed to assess executive function usually represent external tasks that are unfamiliar or uncommon and requires an individual to apply certain intellectual abilities (e.g. planning) in order to solve the task/problem (3). The Stroop task is one of the most frequently used executive function measures. A number of modifications of this test (i.e. card-based and computerized) have been used in research and clinical settings. The different conditions of the Stroop task are used to assess a number of executive function components, including selective attention, the ability to shift response/perceptual sets and the ability to inhibit habitual responses (31).

2. Cerebral oxygenation

Frontal lobe function has generally been linked to executive function (11). Near-infrared spectroscopy (NIRS) has been used successfully in research settings to measure changes in older individuals' brain oxygenation during cortical activation. The literature indicates that the Stroop task elicits increased brain activation in the prefrontal cortex and that a Near-infrared (NIR) spectrometer has adequate sensitivity to detect these changes (34). In addition, NIRS is a non-invasive, cost-effective and easy to administer method.

D. Motivation

There is an abundance of literature on preventative measures for age-related health deterioration. Physical activity and exercise have been shown to reverse a number of the detrimental effects of senescence. Longitudinal studies in healthy, older individuals have shown beneficial effects of aerobic and resistance training on submaximal endurance capacity, functional mobility and cognitive function. In addition, resistance training leads to significant gains in muscle strength in this population.

However, there is a need for longitudinal studies comparing the positive influence of aerobic versus resistance training with regards to physical and cognitive function. Additionally, the effect of aerobic interval training on older individuals' cognitive and brain health has not been previously investigated.

Furthermore, no previous study has compared the effects of resistance training, high-intensity interval training and moderate continuous training on aspects of older individuals' physical and cognitive function. In addition, research studies investigating brain oxygenation during cortical activation primarily use cross-sectional study designs. The influence of exercise training on brain activation patterns is inconsistent and not well understood and it remains to be established if these patterns are training mode dependent and/or linked to alterations in cognitive performance. To our knowledge, NIRS has not been used in a longitudinal study to determine the differential influence of exercise training on the cerebral oxygenation response in healthy, older individuals.

Initially, this study was only going to focus on resistance training and its effect on physical and cognitive function to fulfil the requirements for an MSc in Sport Science. It was decided to focus on resistance training due to the fact that far less research is being done on this mode of training, yet it is acknowledged that improvements in muscle mass and strength have beneficial effects on many health-related outcomes in older individuals. At the end of the intervention period it was realized that the study entailed surprising findings with regards to the haemodynamic changes and cognitive function and that it would be worthwhile to compare these responses to aerobic type exercises. The study was subsequently upgraded to a PhD.

E. Purpose and hypotheses

The purpose of this study was to investigate the relation of exercise training mode, brain oxygenation and cognition in healthy older adults. The three articles address the following research questions:

1. Is there a difference in the magnitude of the induced changes in muscle strength and physical function in an older population over the course of a resistance training programme? How are the outcomes affected by a period of detraining?

The hypothesis was that the improvements in muscle strength and physical function are induced in a similar manner over the course of a training and detraining period.

2. Do different exercise training modalities have similar effects on the physical and cognitive function of older individuals?

The hypothesis was that high intensity interval training will have superior effects on the physical and cognitive function in older adults compared to resistance exercise and moderate continuous aerobic training.

3. Does the exercise training mode have a differential effect on older individuals' cerebral oxygenation during cortical activation?

The hypothesis was that high intensity interval training, as a result of greater improvements in aerobic capacity, will affect more efficient cerebral function in older adults compared to resistance training and moderate continuous aerobic training.

METHODOLOGY

A. Study design

This study used a pre-post measures experimental-control research design. The selected participants were randomly allocated to four groups, namely a no-exercise control group and three experimental groups that took part in either a resistance training (RT), high-intensity interval training (HIIT) or moderate continuous training (MCT) exercise intervention over a period of 16 weeks.

B. Participants

1. Participant Selection

The study proposal was approved by the Ethics Committee of Stellenbosch University (HS891/2013) (Appendix A). Participants were recruited via the University website, as well as advertisements in local newspapers. All participants underwent a screening procedure to identify those that meet the inclusion criteria. The subjects were screened for co-morbidities to minimize external influence and possible risks to participants. The co-morbidities were screened by means of cholesterol and glucose tests, anthropometry measures as well as a health questionnaire (Appendix B). Seventy-two inactive men and women, between 55 and 75 years, volunteered to participate in the study. All participants were informed of the purpose of the study and gave full consent to participate (Appendix C).

1.1. Inclusion and exclusion criteria

Participants were included in the study if they were between the ages of 55 and 75 years, had a Body Mass Index of less than 35 $kg.m^{-2}$ and had not been participating in at least 30 minutes of moderate intensity physical activity (64%-76% of maximal heart rate) on at least three days of the week for at least three months. Participants were excluded if they had one or more signs/symptoms of, or diagnosed cardiovascular, pulmonary and/or metabolic diseases, if they experienced orthopaedic or musculoskeletal problems that could affect their exercise ability and if they achieved a Montreal Cognitive Assessment (MoCA) score of less than 26 out of 30 (Appendix D).

C. Sample size

The sample size calculation was based on a type 1 error of 5%, statistical power (1-β) of 80% and a magnitude-based difference of 1.0. for changes in arm and leg muscle strength between RT and CON. Hence it was calculated that a total of 34 participants were needed for the resistance training study (17 per group) (12). The sample size for the comparison in aerobic fitness between the HIIT and MCT groups was similarly calculated, with the exception that a magnitude-based difference of 0.8 was utilized for changes in walking endurance. In this case a total of 24 participants were needed.

D. Statistical analysis

Statistical analysis was performed using STATISTICA 12. Normal probability plots were inspected to assess the normality of the data and check for outliers, and were mostly found to be in order.

Mixed model repeated measures ANOVA was used to analyse the data. The participants were entered in the model as random effects and GROUP and TIME as fixed effects. Main and interaction effects are reported. The covariant structure used was compound symmetry. A *P* value of < 0.05 was considered statistically significant.

E. Participation flow chart

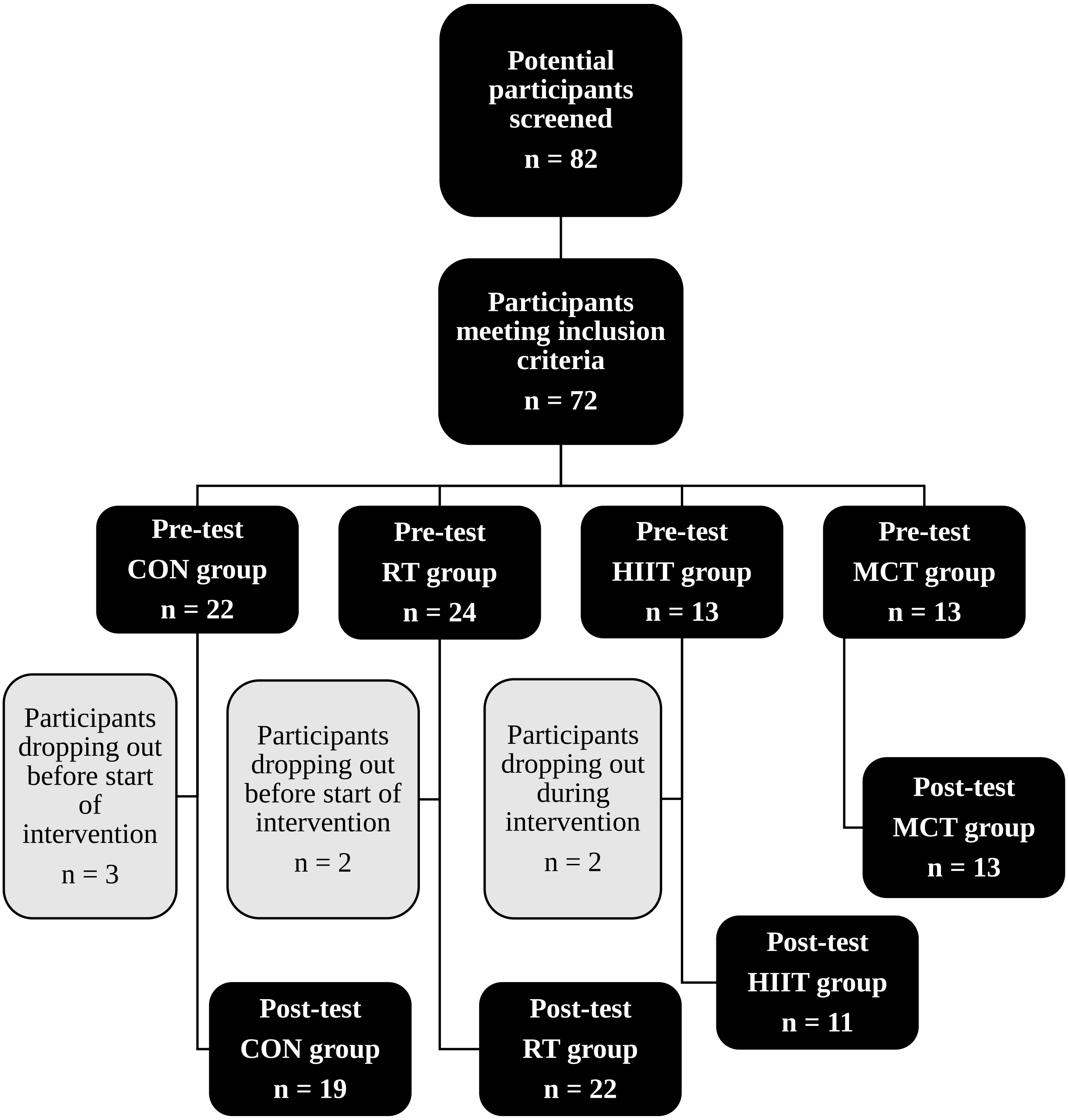

FIGURE 1 – Participation flow chart.

F. Experimental procedures

Fig. 2, 3 and 4 illustrate the study designs, testing protocols and time lines for each article.

1. The time course of changes induced by resistance training and detraining on muscular and physical function in older adults.

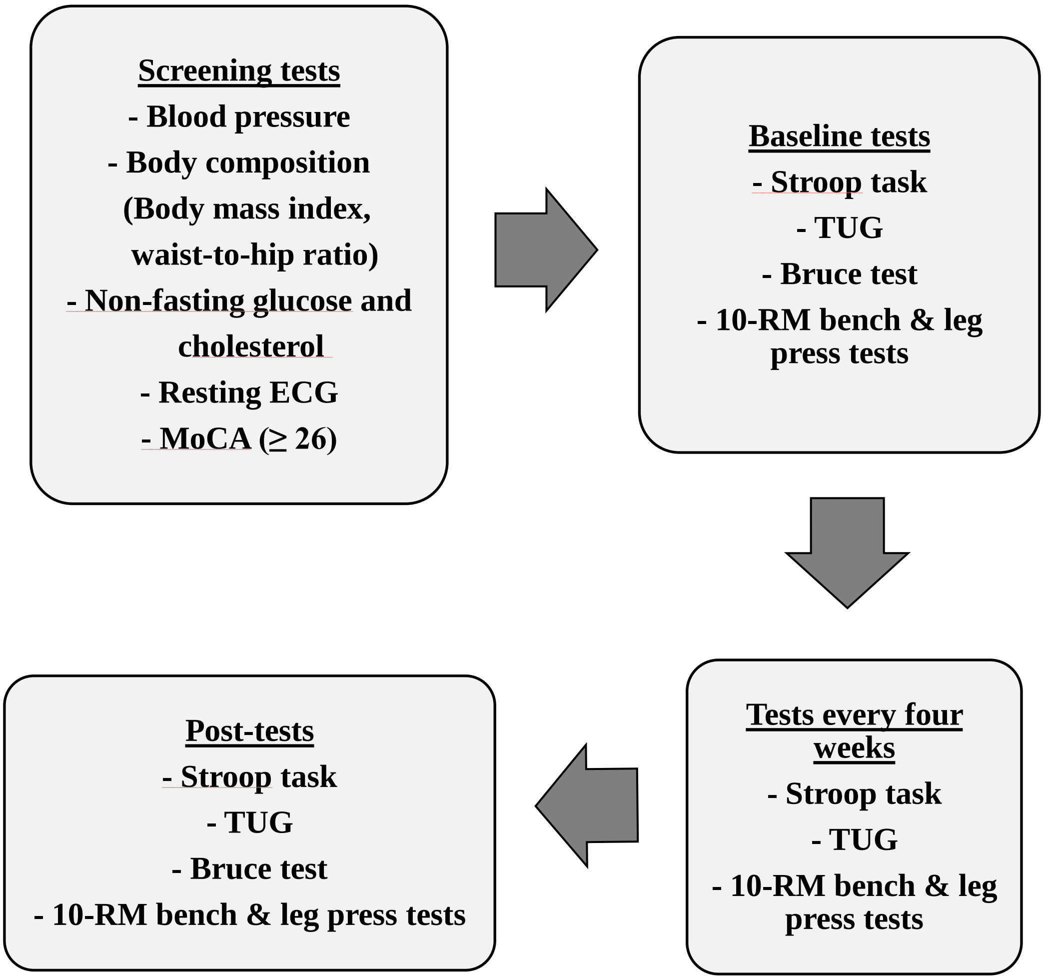

FIGURE 2 – Testing protocol for Article 1 (Chapter 2).

2. The effect of different exercise training modalities on cognitive and physical function in a healthy older population.

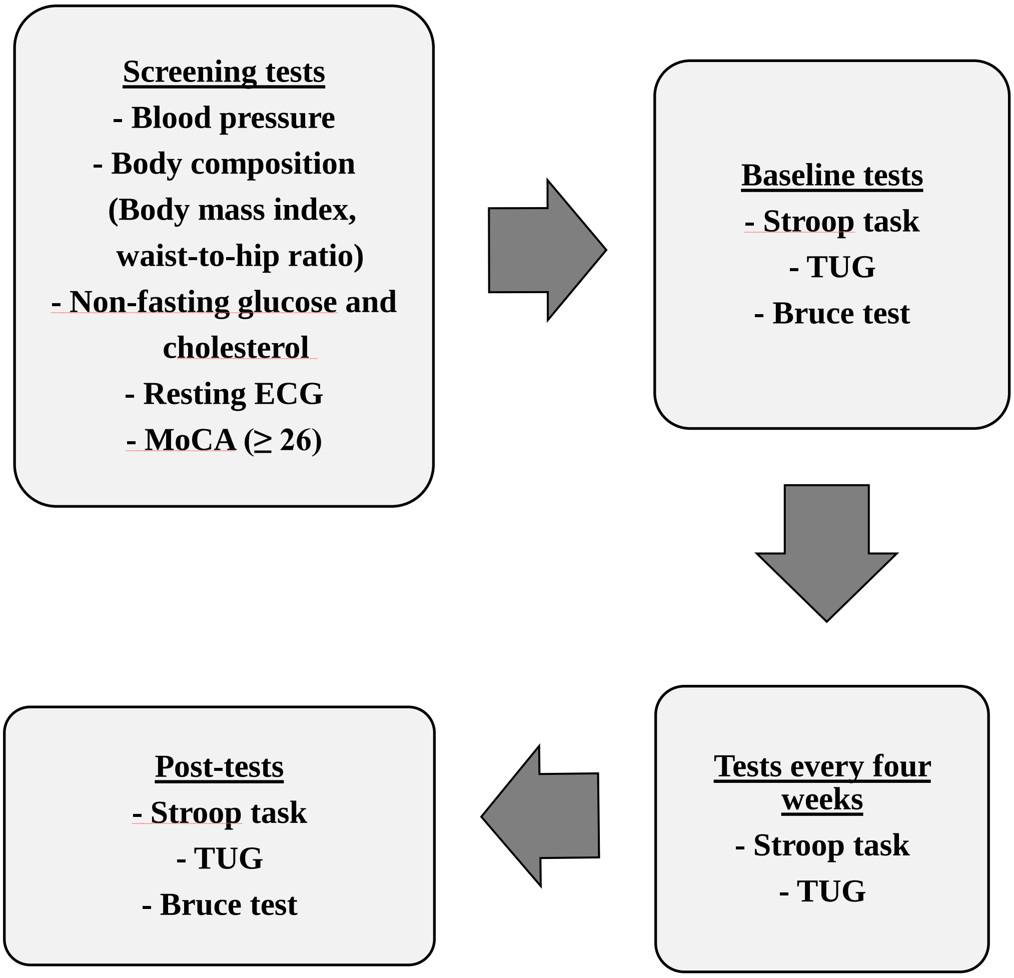

FIGURE 3 – Testing protocol for Article 2 (Chapter 3).

3. Cerebral oxygenation during cortical activation: The differential influence of three exercise training modalities.

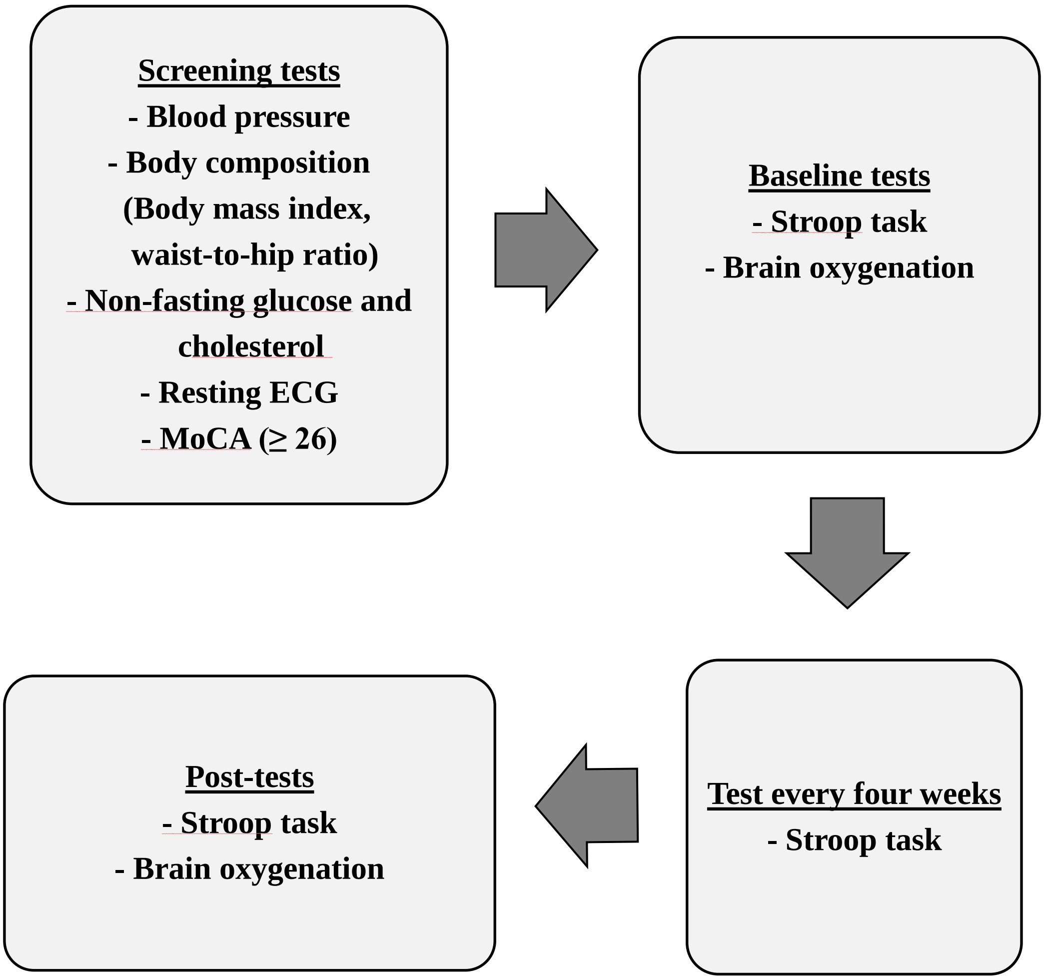

FIGURE 4 – Testing protocol for Article 3 (Chapter 4).

REFERENCES

1. Alves CRR, Gualano B, Takao PP, *et al*. Effects of acute physical exercise on executive functions: a comparison between aerobic and strength exercise. *J Sport Exerc Psychol*. 2012;34(4):539–49.
2. Anderson-Hanley C, Nimon JP, Westen SC. Cognitive health benefits of strengthening exercise for community-dwelling older adults. *J Clin Exp Neuropsychol*. 2010:32(9):996–1001.
3. Ardila A. On the evolutionary origins of executive functions. *Brain Cogn*. 2008;68(1):92–9.
4. Blumenthal JA, Emery CF, Madden DJ, *et al*. Cardiovascular and behavioral effects of aerobic exercise training in healthy older men and women. *J Gerontol A Biol Sci Med Sci*. 1989;44(5):M147–57.
5. Bohannon RW. Reference values for the timed up and go test: a descriptive meta-analysis. *J Geriatr Phys Ther*. 2006;29(2):64–8.
6. Cassilhas RC, Viana VAR, Grassmann V, *et al*. The impact of resistance exercise on the cognitive function of the elderly. *Med Sci Sports Exerc*. 2007:39(8):1401–7.
7. Chang Y-K, Etnier JL. Exploring the dose-response relationship between resistance exercise intensity and cognitive function. *J Sport Exerc Psychol*. 2009;31(5):640–56.
8. Chang Y-K, Tsai C-L, Hung T-M, So EC, Chen F-T, Etnier JL. Effects of acute exercise on executive function: a study with a Tower of London Task. *J Sport Exerc Psychol*. 2011;33(6):847–65.
9. Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci*. 2003;14(2):125–30.
10. Dustman RE, Ruhling RO, Russell EM, *et al*. Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiol Aging*. 1984;5(1):35–42.
11. Etnier JL, Chang Y-K. The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. *J Sport Exerc Psychol*. 2009;31:469–83.
12. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39:175-91.
13. Fleg JL, Morrell CH, Bos AG, *et al*. Accelerated longitudinal decline of aerobic capacity in healthy older adults. *Circulation*. 2005;112(5):674–82.

14. Fox KR. The influence of physical activity on mental well-being. *Public Health Nutr*. 1999;2(3a):411–8.
15. Gibala MJ, Little JP, MacDonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol*. 2012;590(5):1077–84.
16. Goodpaster BH, Park SW, Harris TB, *et al.* The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci*. 2006;61(10):1059–64.
17. Hassmén P, Koivula N, Uutela A. Physical exercise and psychological well-being: a population study in Finland. *Prev Med*. 2000;30(1):17–25.
18. Hingorjo MR, Syed S, Qureshi MA. Role of exercise in osteoporosis prevention - current concepts. *J Pak Med Assoc*. 2008;58(2):78–81.
19. Hood MS, Little JP, Tarnopolsky MA, Myslik F, Gibala MJ. Low-volume interval training improves muscle oxidative capacity in sedentary adults. *Med Sci Sports Exerc*. 2011;43(10):1849–56.
20. Kamijo K, Hayashi Y, Sakai T, Yahiro T, Tanaka K, Nishihira Y. Acute effects of aerobic exercise on cognitive function in older adults. *J Gerontol B Psychol Sci Soc Sci*. 2009;64(3):356–63.
21. Lautenschlager NT, Almeida OP. Physical activity and cognition in old age. *Curr Opin Psychiatry*. 2006;19(2):190–3.
22. Liu CK, Fielding RA. Exercise as an intervention for frailty. *Clin Geriatr Med*. 2011;27(1):101–10.
23. Liu-Ambrose T, Donaldson MG. Exercise and cognition in older adults: is there a role for resistance training programmes? *Br J Sports Med*. 2009;43(1):25–7.
24. Liu-Ambrose T, Nagamatsu LS, Graf P, Beattie BL, Ashe MC, Handy, TC. Resistance training and executive functions: a 12-month randomized controlled trial. *Arch Intern Med*. 2010;170(2):170–8.
25. Liu-Ambrose T, Nagamatsu LS, Voss MW, Khan KM, Handy TC. Resistance training and functional plasticity of the aging brain: a 12-month randomized controlled trial. *Neurobiol Aging*. 2012;33(8):1690–8.
26. Martin CK, Church TS, Thompson AM, Earnest CP, Blair SN. Exercise dose and quality of life: a randomized controlled trial. *Arch Intern Med*. 2009;169(3):269–78.

27. McAuley E, Mullen SP, Hillman CH. Physical activity, cardiorespiratory fitness, and cognition across the lifespan. In: *Social Neuroscience and Public Health*. Springer; 2013 p. 235–52.
28. Moholdt T, Aamot IL, Granøien I, *et al.* Aerobic interval training increases peak oxygen uptake more than usual care exercise training in myocardial infarction patients: a randomized controlled study. *Clin Rehabil*. 2012;26(1):33–44.
29. Moholdt TT, Amundsen BH, Rustad LA, *et al.* Aerobic interval training versus continuous moderate exercise after coronary artery bypass surgery: a randomized study of cardiovascular effects and quality of life. *Am Heart J*. 2009;158(6):1031–7.
30. Nybo L, Sundstrup E, Jakobsen MD, *et al.* High-intensity training versus traditional exercise interventions for promoting health. *Med Sci Sports Exerc*. 2010;42(10):1951–8.
31. Pachana NA, Thompson LW, Marcopulos BA, Yoash-Gantz R. California Older Adult Stroop test (COAST) development of a Stroop test adapted for geriatric populations. *Clin Gerontol*. 2004;27(3):3–22.
32. Payette H, Gueye NDR, Gaudreau P, Morais JA, Shatenstein B, Gray-Donald K. Trajectories of physical function decline and psychological functioning: the Quebec longitudinal study on nutrition and successful aging (NuAge). *J Gerontol B Psychol Sci Soc Sci*. 2011;66(S1):i82–i90.
33. Predovan D, Fraser SA, Renaud M, Bherer L. The effect of three months of aerobic training on Stroop performance in older adults. *J Aging Res*. 2012;2012:1–7.
34. Schroeter ML, Zysset S, Kupka T, Kruggel F, Von Cramon DY. Near-infrared spectroscopy can detect brain activity during a color-word matching Stroop task in an event-related design. *Hum Brain Mapp*. 2002;17(1):61–71.
35. Shephard RJ, Balady GJ. Exercise as cardiovascular therapy. *Circulation*. 1999;99(7):963–72.
36. Smiley-Oyen AL, Lowry KA, Francois SJ, Kohut ML, Ekkekakis P. Exercise, fitness, and neurocognitive function in older adults: the "selective improvement" and "cardiovascular fitness" hypotheses. *Ann Behav Med*. 2008;36(3):280–91.
37. Tjønna AE, Stølen TO, Bye A, *et al.* Aerobic interval training reduces cardiovascular risk factors more than a multitreatment approach in overweight adolescents. *Clin Sci*. 2009;116(4):317–26.
38. Trilk JL, Singhal A, Bigelman KA, Cureton KJ. Effect of sprint interval training on circulatory function during exercise in sedentary, overweight/obese women. *Eur J Appl Physiol*. 2011;111(8):1591–7.

39. Whitehurst M. High-intensity interval training an alternative for older adults. *Am J Lifestyle Med*. 2012;6(5):382–6.
40. Whyte LJ, Gill JMR, Cathcart AJ. Effect of 2 weeks of sprint interval training on health-related outcomes in sedentary overweight/obese men. *Metab Clin Exp*. 2010;59(10):1421–8.
41. Wisløff U, Støylen A, Loennechen JP, *et al.* Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients: a randomized study. *Circulation*. 2007;115(24):3086–94.

Chapter 2: Article 1

The time course of changes induced by resistance training and detraining on muscular and physical function in older adults

Status: Accepted for publication in European Review of Aging and Physical Activity

The time course of changes induced by resistance training and detraining on muscular and physical function in older adults

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ABSTRACT

Background: It is generally recognised that the physical functioning of older adults is enhanced with resistance exercise. The aim of this study was to investigate the time course of changes in upper and lower body muscle strength and physical function in older individuals following a 16 week resistance training (RT) programme and a similar duration detraining (DET) period.

Methods: Forty-one inactive individuals (55 to 75 years) were randomly allocated in a RT group (n=22; three sessions per week) and a control (CON) group (n=19). Muscle strength was assessed with 10RM leg and bench press tests, while the Timed-Up-and-Go (TUG) test was used to measure functional mobility. The Bruce treadmill test determined the participants' submaximal endurance capacity. Data were analysed using mixed model repeated measures ANOVA and $P < 0.05$ was considered statistically significant.

Results: Main treatment effects were found for muscle strength ($P < 0.001$) and functional mobility ($P < 0.05$). Upper and lower body strength generally showed a statistically significant improvement after every four weeks in RT (the increase after 16 weeks being 7.3 ± 4.9 kg and 86.6 ± 44.4 kg, respectively; $P < 0.001$) while TUG performance (-0.2 ± 0.4 s; $P < 0.05$) and submaximal endurance capacity (0.7 ± 0.9 min; $P < 0.001$) only improved after 16 weeks. Although muscle strength decreased after DET, it was still better than at baseline. No significant improvements in any performance variable were observed in CON directly after the intervention period (0-16 weeks) ($P > 0.05$).

Conclusion: A 16-week RT programme has positive effects on both muscular and physical function in older adults, although the time course of these adaptations is different. While the gains in muscle strength and submaximal endurance capacity were not totally lost after DET, functional mobility was completely reversed. Older adults can be reassured that if the need

arises to discontinue RT for a certain period they will still retain a large amount of their acquired muscle strength, as well as a degree of physical function such as walking endurance capacity. The association between leg strength and submaximal endurance capacity strengthens the notion that RT should be incorporated in training and rehabilitation programmes of ageing and frail older adults.

KEYWORDS

MUSCLE STRENGTH, FUNCTIONAL PERFORMANCE, EXERCISE CAPACITY, OLDER ADULTS

BACKGROUND

Muscular function plays an important role in the retention of adequate physical functioning with ageing [1, 2]. An individual's muscle strength capacity also plays an essential role in maintaining an independent lifestyle [3, 4]. The preservation of a sense of independence subsequently results in a reduction in the burden on family, the public health sector and the national economy [5].

A 2012 report by Westcott highlights the benefits of resistance training (RT), which are of particular importance to the elderly population [1]. It was concluded that resistance exercise can reverse or delay age-related declines in physical and mental health. Another important benefit of RT, as stated in a review by Liu-Ambrose & Donaldson [6], is moderating the development of sarcopenia – a phenomenon known to increase fall risk and dependence among the elderly.

As stated in a 2009 ACSM Position Stand, untrained individuals experience the greatest gains in muscle strength when performing three exercise sessions per week [7]. Nakamura et al. [8] recommended three training sessions per week, consisting of a combination of RT, walking and recreational activities, to achieve improvements in functional fitness. Significant increases in 1RM values have been reported after six and 12 weeks of strength training, which was associated with a concomitant increase in functional capacity gains [9, 10, 11]. However, the majority of studies merely test muscle strength and physical function before and after the intervention period [9, 10, 12, 13, 14]. To our knowledge, only one study assessed muscle strength every four weeks during a 16-week training programme. However, the detraining (DET) period was very short (four weeks), only lower body exercises were performed and no measure of functional mobility was included [15]. Thus, the manner in which changes in upper and lower body muscle strength and functional mobility are induced over the course of a resistance training intervention is still not known.

The degree to which the observed improvements in muscle strength and physical function can be maintained after the cessation of RT has not been thoroughly investigated. Researchers report significant losses in muscle strength after several weeks of inactivity following RT interventions, with DET periods ranging from six weeks to 18 months [10, 16, 17]. In some instances, however, the strength measured after DET was still significantly higher than at baseline [16, 17], while others report a complete loss of muscle strength gains at follow-up [10]. Geirsdottir et al. [16] found that TUG performance was maintained after a DET period of six to 18 months. In fact, participants performed functionally better at follow-up than before the start of the intervention.

It is difficult to draw inferences from existing longitudinal studies regarding the time course of changes in older adults' muscular and physical function, as it has not been previously documented collectively. The primary aim of this study was therefore to assess the magnitude of changes in upper and lower body muscle strength, functional mobility and submaximal endurance capacity in older individuals during 16 weeks of RT, as well as a similar duration

DET period. The secondary aim was to determine if there is a difference in the time course of the observed changes during training and DET.

METHODS

Participants

Inactive men and women between 55 and 75 years who volunteered for this pre-post measures experimental-control research study underwent a screening procedure to identify those who met the inclusion criteria. They were screened for co-morbidities to minimize external influences on the training responses and possible risks to themselves. The co-morbidities were assessed by means of non-fasting cholesterol and glucose tests, anthropometry and cardiovascular measures, as well as a health questionnaire. Participants were included in the study if they had a body mass index (BMI) of less than 35 kg/m² and had not been participating in at least 30 minutes of moderate intensity physical activity (64%-76% of maximal heart rate) on at least three days of the week for at least three months, as advised by the ACSM’s Guidelines for Exercise Testing and Prescription [18]. Participants were excluded if they had one or more signs/symptoms of, or diagnosed cardiovascular, pulmonary and/or metabolic diseases, if they experienced orthopaedic or musculoskeletal problems that could affect their exercise ability and if they achieved a Montreal Cognitive Assessment (MoCA) score of less than 26 out of 30. The study proposal was approved by the Ethics Committee of Stellenbosch University (HS891/2013).

Of the 61 subjects who were screened, a total of 46 met the inclusion criteria and were randomly assigned to either a resistance training (RT) group or a non-exercise control (CON) group by means of a randomised block design. All participants were informed of the purpose of the study and gave written consent to participate. Two participants dropped out of the RT group, while three did not want to participate because they were included in the CON group.

Thus, 41 men and women (mean age 62.4 ± 5.3 years; BMI 26.3 ± 3.9 kg/m²) completed the intervention, with 22 participants in the RT group and 19 in the CON group.

Testing protocol

Participants were assessed at six different time points throughout the intervention: at baseline (BL), every four weeks (week 4-12), at the end of the intervention period (week 16) and after a detraining (DET) period of 16 weeks. All participants were asked to maintain their current lifestyle and not make any changes to their level of physical activity and diet. The participants in the CON group were reminded of these conditions at each testing session.

Muscular strength, functional mobility and submaximal endurance capacity were measured as primary outcome variables. Participants were asked to void their bladders and to refrain from smoking, exercise and drinking diuretics like caffeine or alcohol for at least four hours before the tests.

A resting ECG, waist-to-hip ratio, standing height, body mass and the MoCA were administered during the first visit as screening tests. During the second visit (BL-testing) the Timed-Up-and-Go (TUG) test was administered to assess functional mobility. The participant was instructed to sit on a standard chair. On the command "Go", he/she stood up from the chair, walked three meters forward, turned and walked back to the chair. Timing started when the command was given and stopped when the subject was again sitting in the chair. Each participant performed three trials and the fastest time was noted as the final result.

The participant's submaximal endurance capacity was assessed on the h/p/cosmos Saturn treadmill (Nussdorf-Traunstein, Germany) using the modified Bruce protocol. Heart rate was recorded with a Suunto memory belt (Suunto Oy 11/2007, Finland). The test started at an incline of 10 degrees and a speed of 2.7 km/h. The incline and speed were increased incrementally every three minutes until the target heart rate (THR) of 75% of the age-predicted maximal (220-age) was reached. The participant's rating of perceived exertion (RPE) was recorded at the end of each stage and when the THR was reached. Participants then actively cooled down for five minutes at 2.7 km/h and no gradient.

Each participant also completed a familiarization session for the muscle strength tests to ensure proper technique and to avoid the Valsalva manoeuvre. The 10 repetition maximum (10RM) bench press and leg press tests were performed during the third session to determine the maximal upper and lower body muscle strength. These results were used to determine the initial intensity of the resistance exercises of the training programme. An initial light load was estimated, considering the subject's RPE score following the warm-up set, which allowed the individual to complete ten repetitions comfortably. The load was then progressively increased until only 10 repetitions could be completed. The 10RM tests were repeated every four weeks to ensure that participants were exercising at the required intensity for the duration of the intervention period. Exercise sessions commenced from the fourth visit onwards.

Training programme

The intervention was conducted over a period of 16 weeks and participants completed three 40-minute sessions per week. Seven resistance exercises were performed using machines and free weights, alternating muscle groups (incline leg press, bench press, squat, latissimus dorsi pull-down, seated row, seated hamstring curls and a seated shoulder press). Three sets of 10 repetitions were performed for each exercise with a rest period of 30 seconds between each set and 90 seconds between each exercise. The first set was performed at 50% of the individual's 10RM, the second set at 75% and the third set at 100% of the 10RM. After eight weeks the load for each set was increased to 75%, 85% and 100% of the individual's 10RM, respectively. The RPE scale was used to monitor the participants' subjective feeling regarding the intensity of the exercise and this value was recorded after completion of each set. An RPE rating of "moderate" was desired after the first set, followed by "somewhat hard" after the second and "hard" after the third set. Passive stretching concluded each session. The participant's blood pressure was monitored before and after each exercise session as a safety precaution.

Follow-up testing

The DET tests were completed 16 weeks after the post-intervention testing. A total of 19 participants in the RT group and 16 participants in the CON group participated in the follow-up testing. The TUG test, modified Bruce protocol and 10RM bench press and leg press tests were performed.

STATISTICAL ANALYSIS

Statistical analysis was performed using STATISTICA 12. Mixed model repeated measures ANOVA was used to analyse the data. The participants were entered in the model as random effects and treatment and time as fixed effects. Fisher least significant difference (LSD) post hoc testing was used. A P value of < 0.05 was considered statistically significant. Of all the types of post hoc testing one can do, Fisher LSD provide the least protection for multiple testing but it was deemed most appropriate as the post hoc tables contained many comparisons due to the six time points that were included in the design. Other post hoc methods could render too many p-values non-significant in such cases, which in turn creates power issues. Pearson product-moment correlation coefficients and 95% confidence intervals were calculated for the relationships between the change in upper and lower body strength, functional mobility and submaximal endurance capacity [19]. The smallest practically significant correlation was set at $\pm$ 0.1. All values are reported as means ± SD.

RESULTS

There were no statistically significant differences in the baseline (BL) characteristics of the resistance training (RT) and control (CON) groups ($P > 0.05$) (Table 1).

Table 1. Baseline characteristics of the participants (mean ± SD).

Variable	RT group	CON group	Total
N	22	19	41
Age (years)	62.4 ± 5.1	62.5 ± 5.6	62.4 ± 5.3
Height (cm)	167.8 ± 7.8	168.7 ± 7.9	168.2 ± 7.9
Body mass (kg)	73.3 ± 15.5	76.8 ± 13.7	74.9 ± 14.8
BMI ($kg \cdot m^{-2}$)	25.8 ± 4.0	26.9 ± 3.7	26.3 ± 3.9
10RM leg press	70.5 ± 39.4	81.3 ± 41.8	75.5 ± 40.9
10RM bench press	22.7 ± 14.3	21.2 ± 9.0	22 ± 12.2

No statistically significant differences in the physical characteristics of the RT and CON groups at BL ($P > 0.05$).

RT, resistance training; CON, control; BL, baseline; BMI, body mass index; RM, repetition maximum.

Following the 16 weeks of training, the RT group showed a statistically significant increase in lower body strength (86.6 ± 44.3 kg; $P < 0.001$) (Table 2). In fact, the change in muscle strength was statistically significant after each month of training ($P < 0.05$), as depicted in Figure 1A, while no improvement was observed in the CON group (-9.2 ± 17.7 kg; $P > 0.05$). A significant Time x Group interaction was found for lower body strength ($P < 0.001$.)

Table 2. Within-group comparisons for muscle strength, functional mobility and submaximal endurance capacity (mean ± SD).

	Weeks of training					
Variable	**BL**	**4**	**8**	**12**	**16**	**DET**
Lower body strength (kg)						
RT	70.5 ± 39.4	98.9 ± 44.5 [a]	114.8 ± 50.5 [a]	132.5 ± 58.2 [a]	157.1 ± 69.1 [a]	123.7 ± 56.4 [a]
CON	81.3 ± 41.8	81.1 ± 42.8	79.7 ± 42.6	76.6 ± 39.0	72.1 ± 36.1	72.5 ± 33.2 [b]
Interaction effect: $P < 0.001$						
Upper body strength (kg)						
RT	22.7 ± 14.4	25.7 ± 15.4 [a]	27.6 ± 15.1 [a]	27.8 ± 15.0 [a]	30.0 ± 16.4 [a]	25.2 ± 10.8 [a]
CON	21.2 ± 9.0	20.3 ± 8.7	20.4 ± 8.6	20.9 ± 9.8	20.2 ± 8.6	21.5 ± 9.2
Interaction effect: $P < 0.001$						
TUG (s)						
RT	5.4 ± 0.9	5.3 ± 0.8	5.3 ± 0.7	5.5 ± 0.8	5.1 ± 0.8 [b]	5.4 ± 0.8
CON	5.5 ± 1.1	5.6 ± 0.9	5.7 ± 1.0	5.7 ± 0.9	5.7 ± 0.8 [b]	5.6 ± 0.8 [b]
Interaction effect: $P < 0.05$						
Time to THR [Bruce test (min)]						
RT	5.5 ± 1.6				6.2 ± 1.4 [a]	6.4 ± 2.0 [a]
CON	5.8 ± 1.6				5.8 ± 1.6	6.4 ± 1.9 [b]
Interaction effect: $P > 0.05$						

[a]Significantly different from BL ($P < 0.001$).

[b]Significantly different from BL (*P* < 0.05).

BL, baseline; DET, detraining; RT, resistance training; CON, control; TUG, Timed-Up-and-Go; THR, target heart rate.

Although the RT group lost a significant amount of lower body strength after the detraining (DET) period (34.0 ± 23.5 kg; *P* < 0.001) (Table 2), this value was still significantly higher than their BL values (52.6 ± 23.5 kg; *P* < 0.001), as well as the CON group's DET value (*P* < 0.001) (Fig. 1A).

The RT group improved their upper body strength significantly after 16 weeks (7.3 ± 4.9 kg; *P* < 0.001), while no change was observed in the CON group (-1.0 ± 3.6 kg; *P* > 0.05) (Table 2). With the exception of the second to third month, the increase in muscle strength was significant after each month of training (*P* < 0.05). A significant Time x Group interaction was found for upper body strength (*P* < 0.001).

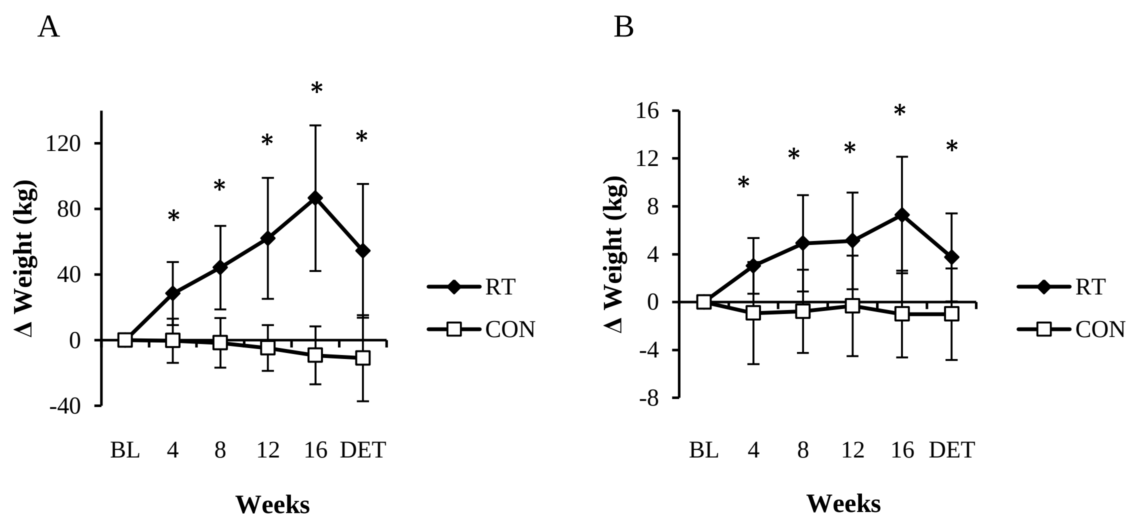

Figure 1. Relative changes in muscle strength. Changes in lower body strength (A) and upper body strength (B) from BL in RT and CON during the 16-week intervention and after the DET period. *Statistically significant between-group differences (*P* < 0.001).

After DET, the RT group's upper body strength decreased significantly (3.8 ± 3.4 kg; *P* < 0.001), but this value was still significantly higher compared to their BL values (3.5 ± 3.4 kg;

P < 0.001) (Table 2). The between-group difference from BL to DET was also statistically significant (increase of 3.5 ± 3.4 kg in RT vs decrease of 1.0 ± 3.3 kg in CON; *P* < 0.001).

The RT group's Timed-Up-and-Go (TUG) performance improved significantly after the intervention period (-0.2 ± 0.4 s; *P* < 0.05), while the CON group experienced a significant decline in TUG performance (0.3 ± 0.4 s; *P* < 0.05) (Table 2). However, after DET the gain in functional mobility in the RT group was completely lost and values were back to BL (*P* > 0.05) (Fig. 2). A significant Time x Group interaction was found for functional mobility (*P* < 0.05).

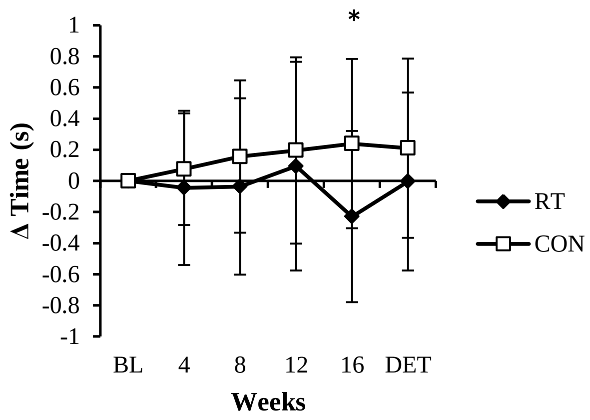

Figure 2. Relative changes in functional mobility. Changes in TUG performance from BL in RT and CON during the 16-week intervention and after the DET period. *Statistically significant between-group difference at post-test (*P* = 0.01).

There was a statistically significant improvement in submaximal endurance capacity in the RT group after the intervention period (0.7 ± 0.9 min; *P* < 0.001), with a further improvement of 0.2 ± 0.9 min after the DET period (*P* < 0.001 from BL) (Table 2). Although the CON group had no change in their submaximal endurance capacity after the intervention period (*P* > 0.05), they performed significantly better after the DET period than at BL (0.6 ± 0.9 min; *P* < 0.05) (Fig. 3). The Time x Group interaction for submaximal endurance capacity did not reach significance (*P* > 0.05).

A moderate positive relationship was found between increases in leg strength and the improvement in submaximal endurance capacity (r = 0.54, CI: 0.27-0.72), while the relationship between increases in arm strength and the improved submaximal endurance capacity was not significant (r = 0.19, CI:-0.13 – 0.47). It is unlikely that gains in leg or arm strength have a meaningful practical influence on the enhancement in functional mobility (TUG) (r = -0.24, CI:-0.51 – 0.07 and r = -0.09, CI: -0.39-0.22, respectively).

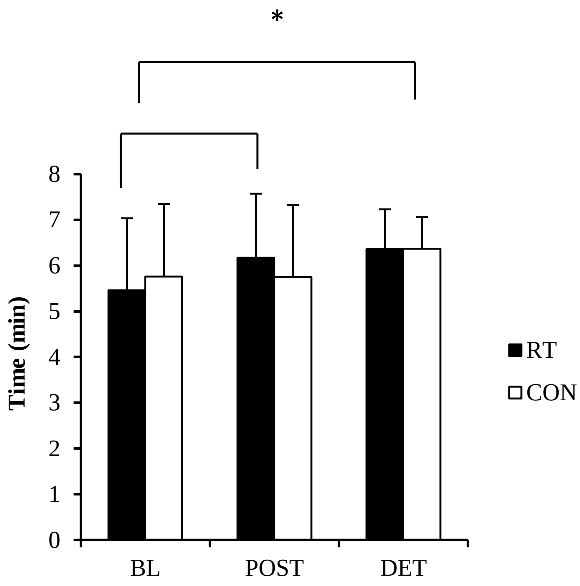

Figure 3. Time to reach target heart rate (THR) during the Bruce treadmill test. No differences were observed between the groups ($P > 0.05$). RT improved their time to reach THR following the intervention period ($P < 0.001$). RT and CON showed an increased time to reach THR after DET compared to BL ($P < 0.05$).

DISCUSSION

Three main findings of this study were that (a) the time course for improvements in upper and lower body muscle strength, functional mobility and submaximal endurance capacity over 16 weeks was different; (b) gains in muscle strength and submaximal endurance capacity were not completely lost after 16 weeks of detraining (DET) and (c) leg muscle strength is an important correlate to submaximal endurance capacity in older individuals.

It was found that both arm and leg muscle strength improved significantly (39 ± 27% and 167 ± 125%, respectively) over the course of 16 weeks in older individuals who had no previous experience in resistance training (RT). The observed changes were already significant after four weeks; thereafter more gains were achieved every four weeks until the completion of the programme. The increase in the participants' leg strength was significant after each month of training, suggesting that the progression in training loads for the leg exercises were well structured for the participants. Furthermore, seeing a steady monthly improvement in muscle strength will very likely be a strong motivating factor for older adults.

The results support previous findings that noteworthy muscle strength increases can be achieved within 12 sessions in ageing individuals [15, 20], irrespective of training frequency per week. Pinto et al. [11] reported an improvement in the leg strength of elderly women after completing 12 lower body strength training sessions, while Lovell et al [15] observed a similar improvement in older men. The latter study also reported a significant improvement in leg strength after each month of training over a 16-week training period. The present study adds to the existing literature by showing that 12 RT sessions result in a marked increase in upper body muscle strength and that after 48 sessions there was still no indication of a plateau in the improvements of both upper and lower body strength.

Modest, but statistically significant improvements in functional mobility [Timed-Up-and-Go (TUG) test] and submaximal endurance capacity during the Bruce test were observed only after 16 weeks of RT (3 ± 10% vs 19 ± 29%, respectively). These results are in contrast with previous findings where significant changes in physical function were evident after a shorter time period. Pinto et al. [11] found significant increases in physical function and muscle strength after six weeks of lower body strength training in elderly women, while others reported improved physical function after 12 weeks RT [9, 10]. The fact that a significant improvement in functional mobility in the current study was only observed at the end of the intervention may possibly be attributed to the fact that the RT programme did not focus exclusively on the leg muscles, but also included arm exercises. Furthermore, studies also vary in terms of training intensities, with this study employing higher exercise intensities than most others. In a meta-analysis Steib et al. [21] concluded that although higher training intensities (> 60% 1RM) lead to greater gains in muscle strength, it is not necessarily more advantageous for improvements in physical function in older adults compared to low and moderate intensity RT. It should also be noted that only Pinto et al. [11] included a control group in their studies. Without a control group one cannot be certain that enhanced performances can be attributed to the training programme alone, as one cannot exclude the possibility of the Hawthorne effect, the learning effect, or normal day-to-day variation as reasons for the findings.

The participants' improvement in submaximal endurance capacity in response to RT is in agreement with previous reports. An increased submaximal endurance capacity after RT could be the result of peripheral adaptations in the trained muscles, which have been reported in other RT studies. Lovell et al [15] found an increase in arterial-venous oxygen difference after 16 weeks of strength training, while cardiac output remained unchanged. Researchers suggested that this increased ability of the muscles to utilize oxygen is the result of increases in capillary density and mitochondria in the trained muscles [15, 22]. It has also been proposed that resistance training results in the recruitment of less motor units by the working muscle, consequently prolonging the onset of total muscle fiber fatigue [14, 22].

Even though there was a decrease in the participants' muscle strength at follow-up, their level of strength was still significantly higher than the values obtained at the pre-test. This finding is also in line with previous research. Despite a significant decrease in muscle strength after

20 weeks of DET following an 18-week progressive RT intervention, Harris et al. [17] reported that their participants' muscle strength was still significantly higher compared to baseline values. The same trend was described by Geirsdottir et al. [16], where participants completed DET tests over a period of six to 18 months following a 12-week RT programme. These findings reflect the long lasting effects of well-designed progressive RT programmes and suggest that even if individuals cannot train for a period of time, all is not lost.

Functional mobility returned to pre-training values after 16 weeks of DET, despite the significant retention of leg strength. This finding is in agreement with the results of Correa et al. [10], but in contrast to the findings of Geirsdottir et al. [16]. Both studies investigated the effects of 12 weeks of RT, which was followed by DET periods of 12 months and longer. The inconsistencies in these findings could be a function of the differences in the frequency, duration and intensity of the interventions, as well as the follow-up periods. Furthermore, it should be noted that different functional mobility tests are used in the various studies and it is questionable whether the outcomes for these different tests (i.e. TUG, 30s sit-to-stand, stair climbing etc.) are comparable.

Table 2 shows that there were significant improvements in submaximal endurance capacity in both groups after the follow-up period. However, upon closer inspection of the data it was evident that only two participants in each group showed a pronounced improvement from post-test to DET [19.5% and 28% in RT group and 67.2% and 24.8% in control (CON) group], consequently affecting the group's overall results. When these outliers are omitted from the data set, it shows that both groups did indeed perform better after DET, however, the improvements in performance were not statistically significant.

Our findings suggest that enhanced leg muscle strength is a better determinant of submaximal endurance capacity, than of functional mobility as assessed by the TUG test. This is probably because performance in the TUG test is more dependent on coordination, balance and reaction time, which are not necessarily enhanced by RT.

This is the first study to show that gains in functional mobility and muscle strength do not happen simultaneously. Whereas upper and lower body strength was significantly enhanced after four weeks, the improvement in functional mobility was only evident after 16 weeks. Longer term intervention studies (> four weeks) only reported pre- and post-training results and therefore it is unclear if this finding is unusual. It is not clear if this pattern is a function of our specific training programme, whether it is due to differences in the time course of physiological adaptations (i.e. peripheral and central adaptations), whether it is a finding limited to our population (i.e. low strength levels, but higher levels of functional mobility at the beginning of the study), or if it is a function of the sensitivity of the selected physical tests to change. According to the relative norms for upper and lower limb strength [18], the participants' overall muscle strength was below average for men and women in both the 50-59 and greater than 60 years age categories prior to the intervention, while their TUG results were above average [23]. Therefore, the participants in this study had greater capacity to improve their muscular function than their functional mobility. Future studies should determine if participants with lower levels of functional mobility show similar patterns of change over the course of a physical intervention programme compared to the current study.

CONCLUSION

The findings of the present study demonstrate that a 16-week RT intervention in ageing individuals is associated with significant improvements in upper and lower body muscle strength, as well as physical function, however, these changes do not come about concurrently. Older individuals can be reassured that if the need arises to discontinue RT for a certain period they will still retain a large amount of their acquired muscle strength, as well as a degree of physical function such as walking endurance capacity. The association between leg strength and submaximal endurance capacity strengthen the notion that RT should be incorporated in training and rehabilitation programmes of ageing and frail older adults.

STUDY LIMITATIONS

Differences in the baseline levels of the experimental group's muscle strength and functional capacity could be considered a limiting factor, due to the possible ceiling effect on the TUG test. Furthermore, the TUG test might not have adequate sensitivity to detect changes in functional mobility in a sample consisting of highly functional older adults. The omission of a test for functional mobility as an inclusion criterion adds another limitation to this study and should be considered in future investigations.

A specific measure of the participants' upper body physical function was also not included; however, the TUG test was included as it is universally recognised as a good determinant of overall functional mobility.

REFERENCES

1. Westcott WL. Resistance training is medicine: effects of strength training on health. Curr Sports Med Rep. 2012;11(4):209–16.
2. Reid KF, Fielding RA. Skeletal muscle power: a critical determinant of physical functioning in older adults. Exerc Sport Sci Rev. 2012;40(1):4–12.
3. Mayer F, Scharhag-Rosenberger F, Carlsohn A, Cassel M, Müller S, Scharhag J. The intensity and effects of strength training in the elderly. Dtsch Arztebl Int. 2011;108(21):359–64.
4. Hunter, GR, McCarthy JP, Bamman MM. Effects of resistance training on older adults. Sports Med. 2004;34(5):329–48.
5. Davis JC, Marra CA, Robertson MC, Khan KM, Najafzadeh M, Ashe MC, et al. Economic evaluation of dose-response resistance training in older women: a cost-effectiveness and cost-utility analysis. Osteoporos Int. 2011;22(5):1355–66.
6. Liu-Ambrose T, Donaldson MG. Exercise and cognition in older adults: is there a role for resistance training programmes? Br J Sports Med. 2009;43(1):25–7.
7. American College of Sports Medicine. Position Stand: Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009;41(6):687–708.
8. Nakamura Y, Tanaka K, Yabushita N, Sakai T, Shigematsu R. Effects of exercise frequency on functional fitness in older adult women. Arch Gerontol Geriatr. 2007;44(2):163–73.
9. Arnarson A, Geirsdottir OG, Ramel A, Briem K, Jonsson PV, Thorsdottir I. Effects of whey proteins and carbohydrates on the efficacy of resistance training in elderly people: double blind, randomised controlled trial. Eur J Clin Nutr. 2013;67(8):821–6.
10. Correa CS, Cunha G, Marques N, Oliveira-Reischak Ã, Pinto R. Effects of strength training, detraining and retraining in muscle strength, hypertrophy and functional tasks in older female adults. Clin Physiol and Funct Imaging. 2015:1–5.
11. Pinto RS, Correa CS, Radaelli R, Cadore EL, Brown LE, Bottaro M. Short-term strength training improves muscle quality and functional capacity of elderly women. AGE. 2014;36(1):365–72.
12. Ades PA, Ballor DL, Ashikaga T, Utton JL, Nair KS. Weight training improves walking endurance in healthy elderly persons. Ann Intern Med. 1996;124(6):568–72.

13. Henwood, TR, Taaffe DR. Short-term resistance training and the older adult: the effect of varied programmes for the enhancement of muscle strength and functional performance. Clin Physiol Funct Imaging. 2006;26(5):305–13.
14. Parker ND, Hunter GR, Treuth MS, Kekes-Szabo T, Kell SH, Weinsier R, et al. Effects of strength training on cardiovascular responses during a submaximal walk and a weight-loaded walking test in older females. J Cardiopulm Rehabil. 1996;16(1):56–62.
15. Lovell D, Cuneo R, Delphinus E, Gass G. Leg strength and the $\dot{V}O_{2max}$ of older men. Int J Sports Med. 2011;32(4):271–6.
16. Geirsdottir OG, Arnarson A, Ramel A, Briem K, Jonsson PV, Thorsdottir I. Muscular strength and physical function in elderly adults 6-18 months after a 12-week resistance exercise program. Scand J Public Health. 2015;43(1):76–82.
17. Harris C, DeBeliso M, Adams KJ, Irmischer BS, Spitzer Gibson TA. Detraining in the older adult: effects of prior training intensity on strength retention. J Strength Cond Res. 2007;21(3):813–8.
18. American College Of Sports Medicine. ACSM'S Guidelines for Exercise Testing and Prescription. 8th ed. Philadelphia: Lippincott Williams & Wilkens; 2010.
19. Hopkins WG. Calculating likely (confidence) limits and likelihoods for true values (Excel spreadsheet). In: A new view of statistics. sportsci.org: Internet Society for Sport Science. 2002. http://sportsci.org/resource/stats/xcl.xls. Accessed 22 April 2015.
20. Sousa N, Sampaio J. Effects of progressive strength training on the performance of the functional reach test and the timed get-up-and-go test in an elderly population from the rural north of Portugal. Am J Hum Biol. 2005;17(6):746–51.
21. Steib S, Schoene D, Pfeifer K. Dose-response relationship of resistance training in older adults: a meta-analysis. Med Sci Sports Exerc. 2010;42(5):902–14.
22. Frontera WR, Meredith CN, O'Reilly KP, Evans WJ. Strength training and determinants of VO2max in older men. J Appl Physiol. 1990;68(l):329–33.
23. Bohannon RW. Reference values for the timed up and go test: a descriptive meta-analysis. J Geriatr Phys Ther. 2006;29(2):64–8.

Chapter 3: Article 2

The effect of different exercise training modalities on cognitive and physical function in a healthy older population

Status: To be submitted to Medicine & Science in Sports & Exercise

The effect of different exercise training modalities on cognitive and physical function in a healthy older population

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ABSTRACT

Background: Older adults are encouraged to participate in regular physical activity to counter the age-related declines in physical and cognitive health. Literature on the effect of different exercise training modalities (aerobic vs resistance) on these health-related outcomes is not only sparse, but results are also inconsistent. In general it is believed that both acute and chronic aerobic and resistance exercise have a positive effect on executive cognitive function mainly because of the physiological adaptations through increases in fitness. Indications are that HIIT is a potent stimulus to improve cardiovascular fitness, even in older adults; however, its effect on cognitive function has not been studied before.

Purpose: The primary aim of this study was to compare the effects of resistance training, high-intensity interval training and moderate continuous training on the cognitive and physical functioning of healthy older adults.

Methods: Sixty seven inactive individuals (55 to 75 years) volunteered for this intervention study. Participants were allocated to a resistance training (RT) group (n=22), high-intensity interval training (HIIT) group (n=13), moderate continuous training (MCT) group (n=13) and a control (CON) group (n=19). Each training group performed three supervised exercise sessions per week for a period of 16 weeks. Every four weeks cognitive function was assessed with a computerized Stroop task and physical function was assessed with the Timed-Up-and-Go (TUG) test and submaximal Bruce treadmill tests. The latter test, measuring walking endurance, was only completed at baseline and after 16 weeks. Data were analysed using mixed model repeated measures ANOVA and $P < 0.05$ was considered statistically significant. Cohen's effect sizes were calculated to compare the magnitude of differences in outcome variables between the groups.

Results: The HIIT and RT groups showed large practically significant improvements beyond the 4-week intervention period on the Incongruent and Interference Stroop tasks (ES = 1.46 and 1.07 for Incongruent; 1.10 and 1.05 for Interference, respectively), while the MCT group showed a moderate practically significant improvement on the Incongruent task (ES = 0.73) and a large improvement on the Interference task (ES = 1.00). The HIIT group also showed the largest practically significant increase in walking endurance (ES = 0.91) and functional mobility (ES = 0.36). The RT group experienced greater gains in walking endurance compared to the MCT group (ES = 0.48 vs ES = 0.16).

Conclusion: HIIT proved to be superior to RT and MCT for the enhancement of older individuals' executive cognitive control and physical function. These findings support previous suggestions on a possible relationship between increased cardiovascular fitness and cognition. Furthermore, it is proposed that training programmes of shorter durations and higher intensities should be further investigated for its beneficial effects on older adults' mental and physical health.

Key Words: EXECUTIVE FUNCTION, AEROBIC FITNESS, FUNCTIONAL CAPACITY, STROOP TASK, OLDER ADULTS

BACKGROUND

Ageing in humans is associated with a decrease in cognition and an increase in the risk of developing dementia in most individuals (20). The positive effect of physical activity on physical and mental health is well-known. Published studies have shown that regular physical activity during adulthood has a significant and lasting impact on cognition (28). Although an acute bout of exercise positively affects executive cognitive performance, regular exercise during midlife has a protective effect against cognitive decline in the later adult years.

Executive cognitive control has been a topic of interest over many years. Etnier & Chang (9) described executive function as “a higher order cognitive ability that controls basic, underlying cognitive functions for purposeful, goal-directed behaviour and that has been associated with frontal lobe activity.” Executive function specifically refers to the domains of cognitive function that involve executive control, including planning, scheduling, working memory, interference control and task coordination (18). Conceptually, executive function is considered critical for performance in novel situations or when an individual is required to inhibit a previously learned response (9).

Miyake *et al.* (24) used psychometric methods to identify three unique subcomponents of executive function, namely mental set shifting, information updating and monitoring (i.e. working memory) and the inhibition of dominant/automatic responses. Fisk & Sharp (10) added a fourth executive ability, namely word fluency performance, which is argued to reflect how effective individuals access their long-term memory.

McAuley *et al.* (23) reported that a decline in executive cognitive control is associated with the normal ageing process. This proposed decline has been associated with changes (e.g. volumetric) in certain brain areas, especially the frontal lobes. Additionally, Royall *et al.* (29) demonstrated in a three year cohort study that the regression in executive cognitive control is independently associated with longitudinal declines in functional status.

Recently, there has been growing interest in the promotion of physical activity to improve cognitive function and there is mounting evidence that exercise can positively influence this construct and aid in its preservation. The majority of longitudinal studies focus on the effect of a single exercise training modality on executive cognitive function, i.e. aerobic (4, 8, 27) or resistance (2, 5, 21, 22) exercise. Studies comparing the effects of aerobic and resistance training on cognitive function are in the minority, nevertheless from what is known so far, it would seem that aerobic training yield the best results (17, 30). However, the resistance training programmes in these studies consisted of stretching and toning exercises and it could be argued that the intensity was too low to induce significant results. Additionally, to our knowledge, the effect of high-intensity interval training (HIIT) on older adults' cognitive performance has not been investigated previously.

Researchers established that progressive resistance training once or twice weekly for 12 months improved selective attention and conflict resolution in senior women, as measured by the Stroop task (21). This training programme also led to an improvement in response inhibition, as assessed by the Flanker task (22). Forte *et al.* (11) reported that twice weekly resistance training, performed by older individuals for 12 weeks, had a positive effect on the executive function of inhibition, whereas Liu-Ambrose *et al.* (19) observed an improved response inhibition in older adults with a recent history of falls after a 6-month home-based resistance and balance training programme.

Cassilhas *et al.* (5) reported that 24 weeks of moderate- and high intensity resistance exercise programmes had equally beneficial effects on short- and long-term memories, executive function and attention. Anderson-Hanley *et al.* (2) observed positive effects on the Stroop Colour-Word task in older adults after four weeks of resistance training at a low intensity. However, no beneficial effect was found for information processing speed (a lower level cognitive process).

In some instances the improvements in cognition, as induced by a resistance training programme, are not evident for all three measures of executive function (2); reiterating claims that certain components of executive function appear to be more likely influenced by strengthening exercises than other executive function components. Thus, the existing literature indicates that not only does resistance training have a selective effect on cognition (higher vs lower level processes), but also on the subcomponents of executive function, irrespective of the intensity of the exercise (2, 5).

The notion that exercise has a selective effect on cognitive function also seems true for aerobic exercise (7, 17). It was suggested that aerobic training improves performance on tasks which demand greater executive control processes, whereas tasks that do not require a great executive control component remain unaffected. Researchers have also investigated the relationship between physical function and cognition, reporting a link between increased functional capacity and cognitive performance. Liu-Ambrose *et al.* (21) found a significant positive correlation ($r = 0.24$; $P < 0.01$) between increased gait speed and executive cognitive function. Strength and balance training have also been reported to reduce older adults' risk for falling by enhancing cognitive performance (19).

Aerobic training interventions generally have a more profound impact on cardiovascular fitness compared to resistance training (8, 30). However, HIIT has been shown to induce larger increases in maximal aerobic capacity (VO_{2max}) compared to aerobic training at a constant intensity (13, 16). Consequently, as cardiovascular fitness has been proposed as a mediating factor in the enhancement of cognitive performance (27), the question regarding the effect of HIIT on cognition is a matter of interest.

Therefore, the present study aimed to determine if different exercise training modalities (resistance training, high-intensity interval training and moderate continuous training) have similar effects on the cognitive function of older individuals. Furthermore, the effects of the different training interventions on walking endurance and functional mobility were investigated.

METHODS

Participants

Inactive men and women between 55 and 75 years old who volunteered for this study underwent a screening procedure to identify those who met the inclusion criteria for study participation. Individuals were included if they: (a) had a body mass index (BMI) of less than 35 kg/m^2; and (b) had not been participating in at least 30 minutes of moderate intensity physical activity (64%-76% of maximal heart rate) on at least three days of the week for the previous three months. Participants were excluded if they: (a) had one or more signs/symptoms of, or diagnosed cardiovascular, pulmonary and/or metabolic diseases; (b) if they experienced orthopaedic or musculoskeletal problems that could affect their exercise ability; and (c) if they achieved a Montreal Cognitive Assessment (MoCA) score of less than 26 out of 30. The study proposal was approved by the Ethics Committee of Stellenbosch University (HS891/2013).

Of the 82 volunteers who were screened, 72 met the inclusion criteria and were assigned to either a resistance training (RT) group, high-intensity interval training (HIIT) group, moderate continuous training (MCT) group or a non-exercise control (CON) group by means of a randomised block design. All participants were informed of the purpose of the study and gave written consent to participate. Two participants dropped out of the RT group, while three did not want to participate because they were included in the CON group. Two participants dropped out of the HIIT group as a result of injury (unrelated to the study). However, their data were included in the data set until the point of departure. Thus, 67 men and women (mean age 62.7 ± 5.7 years; BMI 26.4 ± 4.0 kg/m^2) completed the intervention, with 22 participants in the RT group (male/female ratio: 7/15), 13 in the HIIT group (male/female ratio: 3/10), 13 in the MCT group (male/female ratio: 3/10) and 19 in the CON group (male/female ratio: 8/11).

Testing protocol

Cognitive performance and physical function were measured as primary outcome variables. Participants were assessed at five different time points: at baseline (BL), every four weeks during training (week 4-12) and at the end of the intervention period (week 16). Participants were asked to refrain from smoking and exercise for at least four and twelve hours, respectively, before the tests as well as to maintain their current lifestyle and not make any changes to their level of physical activity and diet.

A resting ECG, waist-to-hip ratio, BMI and the MoCA were administered during the first visit as screening tests. During the second visit (BL-testing) cognitive performance was assessed with a computerized Stroop task, which consisted of two blocks of increasing difficulty. Each block consisted of 24 trials during which the participant had to respond to a pre-determined command given at the beginning of the block. The first trial of each block served as familiarization to the specific condition. The stimulus was presented on the centre of a laptop screen with the two responses situated at the bottom left and right of the screen. Participants were instructed to use only the left and right arrow keys when responding to the stimulus. They were also given a choice with regards to the language (English or Afrikaans) in which they wanted to complete the task.

Initially, participants had to identify the colour of a rectangle with the choices written in black ink (Stroop Colour/Neutral). The next condition (Stroop Incongruent) required participants to identify the ink colour of a word written in incongruent coloured inks (e.g. the word “blue” printed in red ink), with the choices written in black ink. Participants’ reaction time and accuracy were measured for each trial. The colour subtask evaluated speed of information processing, whereas the incongruent colour-word subtask assessed components of executive function. Stroop Interference was calculated by subtracting the reaction time for the Neutral condition from the reaction time for the Incongruent condition.

The Timed-Up-and-Go (TUG) test was administered to assess functional mobility. The participant was instructed to sit on a standard chair. On the command “Go”, he/she stood up from the chair, walked three meters forward, turned and walked back to the chair. Timing started when the command was given and stopped when the individual was again sitting in the chair. Each participant performed three trials and the fastest time was noted as the final result.

The participant’s walking endurance was assessed on the h/p/cosmos Saturn treadmill (Nussdorf-Traunstein, Germany) using the modified Bruce protocol. Heart rate was recorded with a Suunto memory belt (Suunto Oy 11/2007, Finland). The test started at an incline of 10 degrees and a speed of 2.7 km/h. The incline and speed were increased incrementally every three minutes until the target heart rate (THR) of 75% of the age-predicted maximal (220-age) was reached. The participant’s rating of perceived exertion (RPE) was recorded at the end of each stage and when the THR was reached. Participants then actively cooled down for five minutes at 2.7 km/h at zero incline. Peak oxygen uptake (VO_{2peak}) was estimated from participants’ walking endurance time (minutes) using the formula of Foster *et al.* (12): VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$) = 14.760 – 1.379 (time) + 0.451 ($time^2$) – 0.012 ($time^3$).

Training programmes

The intervention was conducted over a period of 16 weeks and participants completed three training sessions per week. Upper and lower body resistance exercises were performed using machines and free weights. Three sets of 10 repetitions were performed at 50%, 75% and 100% of the individual’s 10 repetition maximum (RM). After eight weeks the load for each set was increased to 75%, 85% and 100% of the individual's 10RM. The MCT group performed continuous walking on a treadmill at 70 – 75% of maximal heart rate (HRmax) for 47 minutes. The HIIT group performed four intervals of four minutes treadmill walking at 90 – 95% HRmax, interspersed by three minute active recovery periods at 70% HRmax. The speed and inclination of the treadmill were continuously adjusted to ensure that participants trained at the correct intensity. The duration of each RT and HIIT session was approximately 30 minutes, excluding the warm-up and cool down.

STATISTICAL ANALYSIS

Statistical analysis was performed using STATISTICA 12. Normal probability plots were inspected to assess the normality of the data and check for outliers, and were mostly found to be in order.

Mixed model repeated measures ANOVA was used to analyse the data. The participants were entered in the model as random effects and GROUP and TIME as fixed effects. A P value of < 0.05 was considered statistically significant. Cohen's effect sizes (ES) were calculated to compare the magnitude of differences in outcome variables between the experimental groups. Cohen's thresholds of 0.2, 0.5, 0.8 and 1.2 were interpreted as small, moderate, large and very large effects, respectively (6). Data are reported as means ± SD.

A few participants in the HIIT (n = 6) and MCT (n = 5) groups had experience in the Stroop task from a previous study a year before and it was discovered that there was a significant carry-over effect on their Stroop task performance after one year. These individuals were subsequently excluded from the cognitive function data set, but they were included in the analysis of the physical function data. Due to an initial learning effect exhibited by all the study groups after the first month of the intervention, the Stroop reaction time analyses were additionally performed without the first month's data (i.e. from week 4 to week 16).

RESULTS

Cognitive function

All participants achieved a MoCA score of more than 25 out of 30, indicating normal cognitive functioning. There were no statistically significant differences in the baseline (BL) physical and physiological characteristics of the groups ($P > 0.05$) (Table 1).

TABLE 1. Baseline characteristics of the participants (mean ± SD).

Variable	CON	RT	HIIT	MCT
N	19	22	13	13
Gender ratio (M:F)	8:11	7:15	3:10	3:10
Age (years)	62.5 ± 5.6	62.4 ± 5.1	64.5 ± 6.3	61.6 ± 5.8
Height (cm)	168.7 ± 7.9	167.8 ± 7.8	166 ± 8.9	163.5 ± 8.6
Body mass (kg)	76.8 ± 13.7	73.3 ± 15.5	73.8 ± 13.7	71.0 ± 14.4
BMI ($kg \cdot m^{-2}$)	26.9 ± 3.7	25.8 ± 4.0	26.6 ± 4.0	26.5 ± 4.2
VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	20.1 ± 4.0	19.4 ± 3.5	17.3 ± 3.2	19.2 ± 6.0
MoCA score	28.2 ± 1.6	27.5 ± 1.3	27.9 ± 1.5	27.6 ± 1.3

No statistically significant differences in the physical characteristics of the groups at BL ($P > 0.05$).

CON, control; RT, resistance training; HIIT, high-intensity interval training; MCT, moderate continuous training; BL, baseline; BMI, body mass index; VO_{2peak}, peak oxygen uptake; MoCA, Montreal Cognitive Assessment.

Reaction time during the Stroop Neutral task

Table 2 depicts the changes in Stroop performance (reaction time and accuracy) for the two different measurement periods (i.e. pre - post and week 4 - post). There were no statistically significant differences at baseline in reaction time between the groups for any of the Stroop subtasks ($P > 0.05$). The HIIT and RT groups showed very large and large practically significant improvements in reaction time from the pre- to post-test on the Stroop Neutral subtask (-4.0 ± 4.7 s vs -4.0 ± 4.4 s; ES = 1.29; $P > 0.05$ and ES = 1.00; $P < 0.05$, respectively), while the MCT and CON groups improved moderately (-1.7 ± 2.0 s vs -2.9 ± 3.0 s; ES = 0.76 and 0.70, respectively; $P > 0.05$). Thus, a statistically significant improvement was only observed for the RT group. Overall, there was a 11.8%, 12.3%, 6.2%

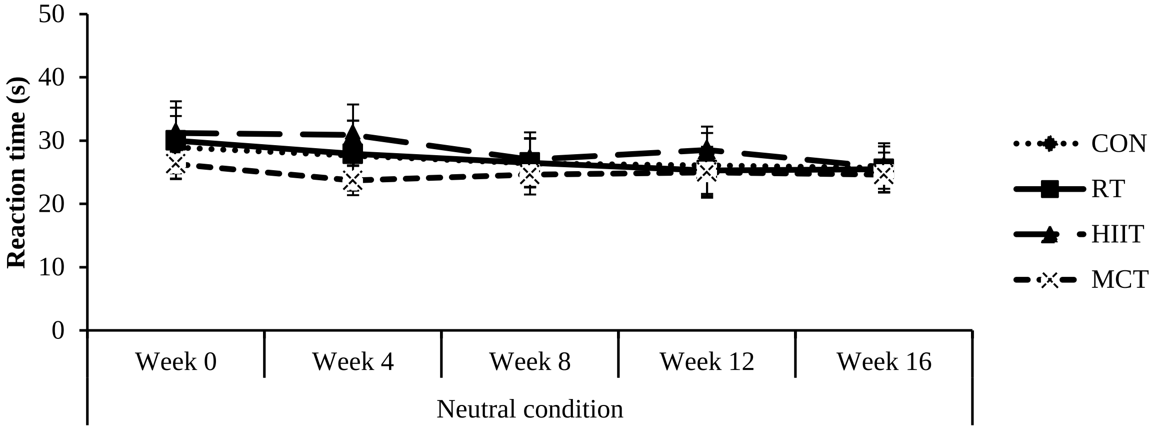
improvement in lower level cognitive function following the HIIT, RT and MCT intervention, while the performance of the CON group improved by 9.2%.

TABLE 2. Comparison of changes in Stroop performance for all the groups (mean ± SD).

	CON			RT			HIIT			MCT		
Subsamples (N)	**19**			**22**			**7**			**8**		
Gender ratio (M:F)	**8:11**			**7:15**			**1:6**			**1:7**		
Pre - Post												
Reaction time (s)												
Stroop condition	% Change	P-value	ES	% Change	P-value	ES	% Change	P-value	ES	% Change	P-value	ES
Neutral	9.2 ± 9.3	0.05	0.70	12.3 ± 12.8	0.00	1.00	11.8 ± 12.2	0.08	1.29	6.2 ± 7.5	0.15	0.76
Incongruent	21.3 ± 15.5	0.01	0.94	24.0 ± 17.9	0.00	1.12	27.5 ± 11.9	0.05	1.51	27.5 ± 5.8	0.00	3.05
Interference	33.0 ± 33.4	0.01	0.95	23.5 ± 62.8	0.00	1.07	49.2 ± 19.2	0.05	1.50	47.6 ± 11.8	0.00	3.26
Accuracy (% correct answers)												
	Pre	Post		Pre	Post		Pre	Post		Pre	Post	
Neutral	99.3 ± 1.6	99.5 ± 1.4		98.6 ± 2.0	99.6 ± 1.3		100 ± 0.0	98.3 ± 2.1		99.4 ± 1.5	98.9 ± 1.9	
Incongruent	98.6 ± 3.2	96.8 ± 3.1		94.0 ± 6.8	96.3 ± 4.9		90.1 ± 7.6	93.5 ± 6.5		97.5 ± 3.2	97.5 ± 2.2	
Week 4 - Post												
Reaction time (s)												
	% Change	P-value	ES	% Change	P-value	ES	% Change	P-value	ES	% Change	P-value	ES
Neutral	4.9 ± 12.0	0.24	0.40	5.3 ± 12.1	0.11	0.52	12.3 ± 8.4	0.09	1.25	4.3 ± 6.0	0.41	0.43
Incongruent	6.8 ± 13.8	0.27	0.37	18.4 ± 13.6	0.00	1.07	18.7 ± 7.8	0.05	1.46	10.8 ± 9.3	0.18	0.73
Interference	8.9 ± 63.9	0.31	0.34	30.0 ± 28.8	0.00	1.05	27.1 ± 32.1	0.13	1.10	31.0 ± 20.3	0.08	1.00
Accuracy (% correct answers)												
	Week 4	Post		Week 4	Post		Week 4	Post		Week 4	Post	
Neutral	99.3 ± 1.6	99.5 ± 1.4		99.4 ± 2.8	99.6 ± 1.3		98.1 ± 3.2	98.3 ± 2.1		99.4 ± 1.5	98.9 ± 1.9	
Incongruent	94.2 ± 4.8	96.8 ± 3.1		94.1 ± 6.6	96.3 ± 4.9		91.3 ± 7.9	93.5 ± 6.5		95.0 ± 3.6	97.5 ± 2.2	

CON, control; RT, resistance training; HIIT, high-intensity interval training; MCT, moderate continuous training; ES, effect size.

A



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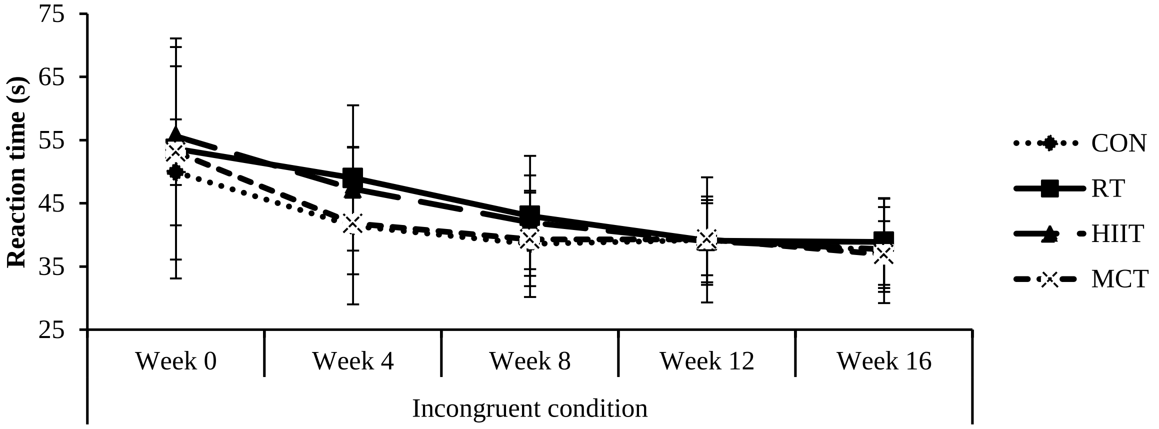

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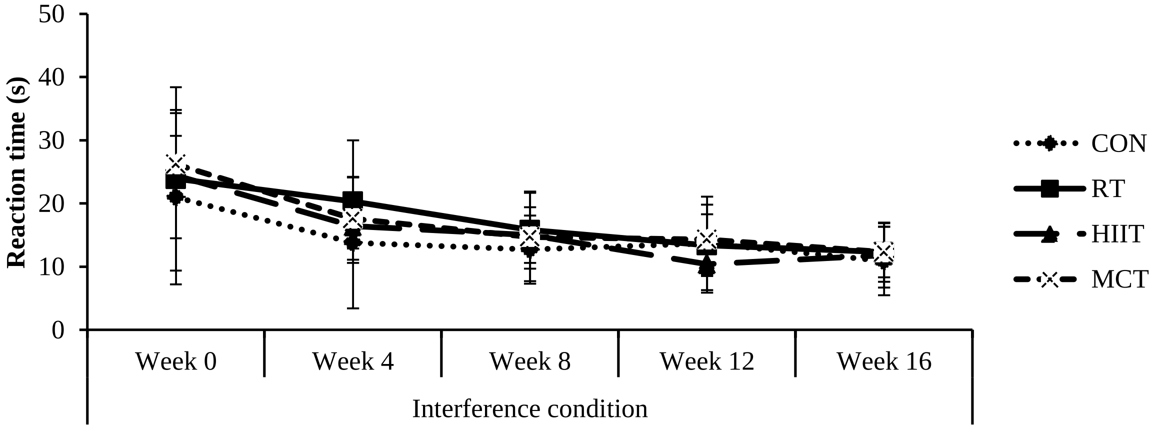

FIGURE 1 – Changes in Stroop reaction time over the 16-week intervention period for (A) the Neutral, (B) the Incongruent and (C) the Interference conditions. Values are means ± SD.

Fig. 1 and Fig. 2 depict the absolute and relative changes in reaction time on the Stroop Neutral, Stroop Incongruent and Stroop Interference subtasks over the course of the 16 week intervention period. Within the first month the MCT group showed a large practically significant improvement in reaction time during the Stroop Neutral condition (26.3 ± 2.3 s vs 23.7 ± 2.3 s; ES = 1.16; $P < 0.05$), followed by a slight decrement in performance up to the end of the intervention (23.7 ± 2.3 s vs 24.6 ± 2.2 s; ES = 0.43; $P > 0.05$). The HIIT group exhibited a very large practically significant improvement in reaction time from week 4 to post-test (30.9 ± 4.8 s vs 25.8 ± 2.3 s; ES = 1.25; $P > 0.05$), with the RT group only showing a moderate practically significant improvement (27.9 ± 5.3 s vs 25.5 ± 3.7 s; ES = 0.52; $P > 0.05$). The magnitude of the improvement in reaction time beyond 4 weeks was considerably smaller in the MCT group compared to the CON group (1.0 ± 1.3 s vs -1.8 ± 3.4 s; ES = 0.95; $P < 0.05$), HIIT group (1.0 ± 1.3 s vs -3.9 ± 3.3 s; ES = 2.33; $P < 0.05$) and RT group (1.0 ± 1.3 s vs -1.8 ± 4.0 s; ES = 0.78; $P > 0.05$). The GROUP x TIME interaction was not significant, however a significant TIME effect was evident at post-test ($P < 0.001$).

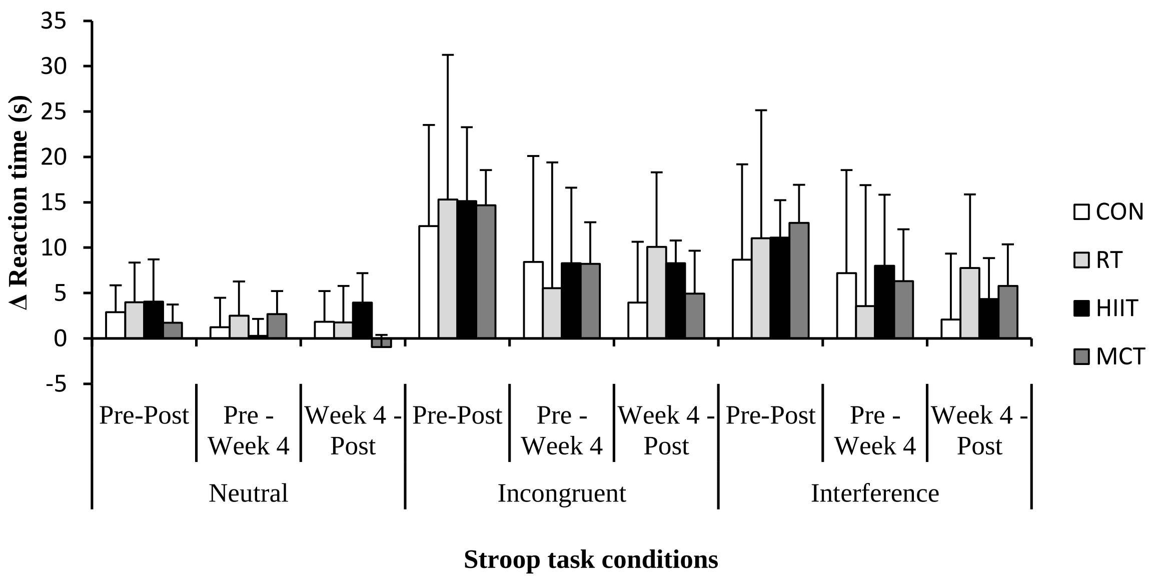

FIGURE 2 – Changes in the Stroop reaction time from baseline (pre) to 16 weeks (post). There were no between-group differences in the change in reaction time, however there was a trend towards significance in Week 4 – Post on the Incongruent condition ($P = 0.06$).

Reaction time during the Stroop Incongruent task

Table 2 shows that there were very large and large practically significant within-group improvements in reaction time during the Incongruent Stroop condition for all the groups over the 16 weeks, with the MCT (-14.7 ± 3.9 s; ES = 3.05; $P < 0.001$) and HIIT (-15.1 ± 8.1 s; ES = 1.51; $P > 0.05$) groups performing practically significantly better than the RT (-15.3 ± 15.9 s; ES = 1.12; $P < 0.001$) and CON groups (-12.4 ± 11.2 s; ES = 0.94; $P < 0.05$). Overall, there was a 27.5%, 24.0%, 27.5% improvement in higher level cognitive function following the HIIT, RT and MCT intervention, while the CON group's performance improved by 21.3%.

The MCT group showed a very large practically significant improvement in reaction time within the first month (-8.2 ± 4.6 s; ES = 1.67; $P < 0.05$), while the reaction time of the CON, RT and HIIT groups improved modestly (-8.4 ± 11.7 s, -5.5 ± 13.9 s, -8.3 ± 8.3 s; ES = 0.57, 0.31 and 0.75, respectively; $P > 0.05$). However, only the exercise groups (HIIT, RT and MCT) showed a further practically meaningful improvement in reaction time over the next 12 weeks (-8.3 ± 2.5 s vs -10.1 ± 8.2 s vs -4.9 ± 4.7 s; ES = 1.46, 1.07 and 0.73, respectively; $P < 0.05$ only for RT), with the CON group improving to a much lesser extent (-3.9 ± 6.7 s; ES = 0.37; $P > 0.05$). Thus, a statistically significant improvement was only observed for the RT group. The magnitude of improvement in reaction time beyond 4 weeks was considerably larger in the RT group compared to the CON group (-10.1 ± 8.2 s vs -3.9 ± 6.7 s; ES = 0.81; $P < 0.05$) and MCT group (-10.1 ± 8.2 s vs -4.9 ± 4.7 s; ES = 0.68; $P > 0.05$), while the HIIT group also performed considerably better than the CON and MCT groups from week 4 to the end (-8.3 ± 2.5 s vs -3.9 ± 6.7 s; ES = 0.69; $P > 0.05$ and -8.3 ± 2.5 s vs -4.9 ± 4.7 s; ES = 0.81; $P > 0.05$, respectively). Overall, the GROUP x TIME interaction was not significant, however a significant TIME effect was evident at post-test ($P < 0.001$).

Reaction time during the Stroop Interference task

An improvement in reaction time was evident in the Stroop Interference condition for all the groups from pre- to post-test, following the same trend that was observed with the Incongruent Stroop condition (Table 2). The MCT and HIIT groups performed practically significantly better (-12.7 ± 4.2 s vs -11.1 ± 4.1 s; ES = 3.26 and 1.50, respectively; $P < 0.001$ only for MCT) compared to the RT and CON groups (-11.0 ± 14.1 s vs -8.7 ± 10.5 s; ES = 1.07 and 0.95, respectively; $P < 0.05$). Overall, there was a 49.2%, 23.5%, 47.6% improvement in executive cognitive function following the HIIT, RT and MCT intervention, while the performance of the CON group improved by 33.0%.

Much of the improvement in the test scores for HIIT and MCT occurred within the first month (-8.0 ± 7.9 s vs -6.3 ± 5.7 s; ES = 1.08 and 1.55, respectively; $P < 0.05$ only for MCT). Further practically meaningful improvements until the end of the intervention were only evident in the HIIT, RT and MCT groups (HIIT: -4.3 ± 4.5 s; ES = 1.10; RT: -7.8 ± 8.1 s; ES = 1.05; MCT: -5.8 ± 4.6 s; ES = 1.00; $P < 0.05$ only for RT). Thus, a statistically significant improvement was only observed for the RT group. The magnitude of the improvement in reaction time beyond 4 weeks was considerably larger in the RT group compared to the CON group (-7.8 ± 8.1 s vs -2.1 ± 7.3 s; ES = 0.74; $P < 0.05$), while the MCT group performed moderately better than the CON group over this time period (-5.8 ± 4.6 s vs -2.1 ± 7.3 s; ES = 0.56; $P > 0.05$). The GROUP x TIME interaction was not significant, however a significant TIME effect was evident at post-test ($P < 0.001$).

Task accuracy for the Stroop Neutral and Incongruent conditions

There were no statistically significant main or interaction effects for task accuracy on the Neutral condition ($P > 0.05$). Table 2 shows the accuracy of the participants during the Neutral and Incongruent conditions of the Stroop task. During the Neutral condition all the participants achieved more than 98% accuracy, with the HIIT and MCT groups performing slightly worse after the intervention (-1.2 ± 2.3% vs -0.5 ± 2.6%; $P > 0.05$). There were no practically significant differences in reaction time on the lower level cognitive task (Stroop Neutral) between the CON and training groups over the last 12 weeks of the intervention period.

There were no statistically significant main or interaction effects for task accuracy on the Incongruent condition ($P > 0.05$). For the Incongruent condition, the participants' accuracy were more than 90%, with the RT and HIIT groups improving their performance after the intervention period. The CON group scored a higher error rate on the Incongruent Stroop task during post-testing (98.6 ± 3.2% vs 96.8 ± 3.1%; ES = 0.55; $P > 0.05$). The largest decrease in task accuracy in the CON group was observed after the first 4 weeks (3.8 ± 5.1%; ES = 1.06; $P < 0.05$), which coincided with their greatest improvement in reaction time (8.4 ± 11.7 s; ES = 0.57; $P > 0.05$) during that specific time period.

Walking endurance and VO_{2peak}

Fig. 3A illustrates the effect of the training programmes on the results of the Bruce treadmill test. There was a large practically significant and statistically significant improvement in walking endurance in the HIIT group after 16 weeks (1.4 ± 1.3 min; ES = 0.91; $P < 0.05$), followed by a near moderate practical significant improvement in the RT group (0.7 ± 0.9 min; ES = 0.48; $P > 0.05$) and a trivial increase in the MCT group (0.6 ± 1.0 min; ES = 0.16; $P > 0.05$). There was no meaningful change in the walking time of the CON group (-0.0 ± 0.7 min; ES = 0.00; $P > 0.05$). Thus, a statistically significant improvement was only observed in the HIIT group. Furthermore, there was a statistically significant GROUP x TIME interaction for walking endurance ($P < 0.05$).

Similar trends were observed for the estimated VO_{2peak} (ml·kg $^{-1}$·min $^{-1}$) values after the intervention period. The HIIT group showed a large practically significant improvement (2.9 ± 2.1 ml·kg $^{-1}$·min $^{-1}$; ES = 0.88; $P < 0.05$) and the RT group a near moderate practically significant improvement (1.7 ± 2.0 ml·kg $^{-1}$·min $^{-1}$; ES = 0.47; $P > 0.05$). There were no practically significant changes in VO_{2peak} in the MCT and CON groups (ES < 0.10; $P > 0.05$).

Functional mobility (TUG)

There was a small practically significant increase in TUG performance in the HIIT group after 16 weeks of training (-0.3 ± 0.4 s; ES = 0.36; $P > 0.05$), compared to the RT (-0.2 ± 0.5 s; ES = 0.27; $P > 0.05$) and MCT (-0.2 ± 0.3 s; ES = 0.27; $P > 0.05$) groups (Fig. 3B). Participants in the CON group performed slightly worse after the intervention period (0.2 ± 0.5 s; ES = 0.13; $P > 0.05$). There was a significant GROUP x TIME interaction for TUG performance ($P < 0.05$).

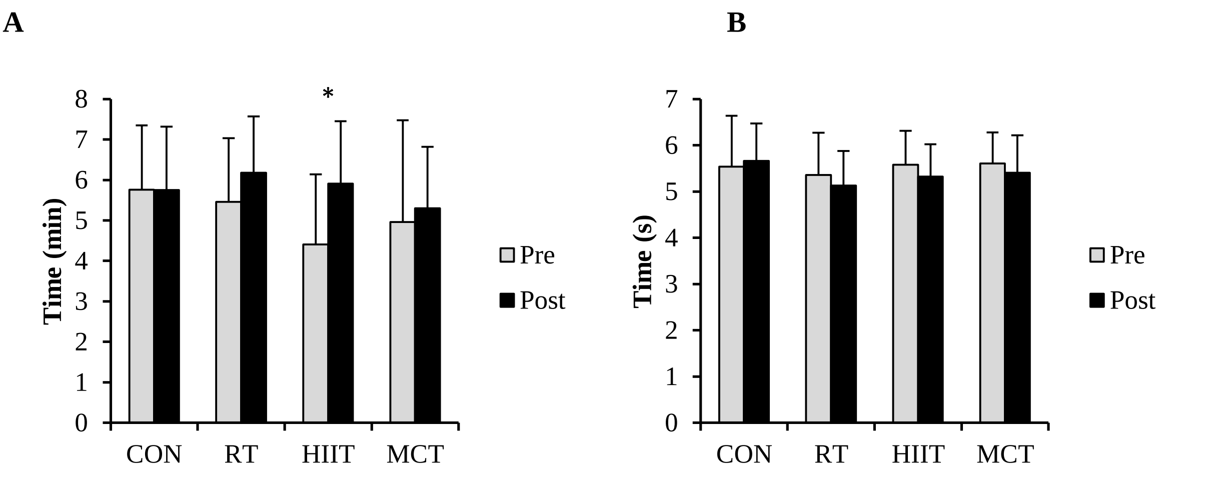

FIGURE 3 – (A) Time to reach target heart rate (THR) during the Bruce treadmill test. No differences were observed between the groups ($P > 0.05$). *Statistically significant improvement in time to reach THR following the intervention period ($P < 0.05$). **(B) Time to complete the Timed-Up-and-Go (TUG) test.** Practically significant improvements were observed in the HIIT (ES = 0.36), RT (ES = 0.27) and MCT (ES = 0.27) groups.

DISCUSSION

To the best of our knowledge, this is the first attempt to compare the effects of three training modes on cognitive function in older adults. One of the primary findings of this study was that only the RT group showed a statistically significant improvement beyond the 4-week intervention period (i.e. 4-16 weeks) on the executive function tasks. However, the same trend was seen for the HIIT and MCT groups, although the latter two groups did not show a statistically significant difference. This was also true for the CON group who improved to a lesser extent. Regarding physical fitness a statistically significant improvement was observed in the walking endurance test for the HIIT group. Here a clear trend was also present for the RT, but not for the MCT and CON groups.

An improvement in reaction time for all the groups was observed on the simple and complex cognitive tasks after the initial month of the intervention, although only the MCT group presented a statistically significant difference. However, as compared to the CON group, only the training groups showed a larger increase beyond the 4-week intervention period on the executive cognitive tasks, although a statistically significant difference was only seen for the RT group. This may suggest that the initial improvements in test scores reflected a learning effect and that the impact of the different training interventions on cognitive function was only evident after the first month of training.

The first key finding is that the results of this study provide partial support for the “selective improvement” hypothesis, as proposed by Kramer *et al.* (17). All three exercise training groups performed better than the CON group on the higher level cognitive tasks, while no differences were evident in the lower level cognitive task (Stroop Neutral) between any of the groups beyond the first month of training.

Accuracy on the two Stroop conditions did not change significantly after the 16-week period in either of the study groups. A significant decrease in accuracy on the Incongruent condition was, however, observed in the CON group after one month, which remained below baseline for the remainder of the intervention period. It is therefore suggested that the CON group's initial improvement in reaction time on the Incongruent Stroop condition could be due to a speed-accuracy trade off.

Our findings are in agreement with previous intervention studies which proposed that exercise has a selective effect on cognition. Researchers observed an improvement in the Stroop Incongruent task in older adults after four weeks of RT, however, the same effect was not found in a task assessing information processing speed (2). Liu-Ambrose *et al.* (21) reported an improvement in the Stroop Interference task after 12 months of RT, compared to balance and tone exercises in community-dwelling older women. Smiley-Oyen *et al.* (30) found an improvement in the Stroop Incongruent task after 10 months of aerobic training in older men and women, but in contrast to the results of the present study, no effect was observed in the strength-and-flexibility training group. This group performed exercises with resistance bands, free weights and stability balls. It could be argued that the intensity of the strength exercises was too low to provide a sufficient stimulus for cognitive improvements. Furthermore, their results could only partly corroborate the "selective improvement" hypothesis, as positive results were not obtained across all the tasks assessing executive function. The researchers neglected to include a no-exercise control group, leading one to question whether the results can be solely attributed to the exercise.

The findings of Predovan *et al.* (27) also provide some support for the hypothesis that aerobic exercise training has a selective effect on cognition. After a 12 week intervention, the training group improved their performance in the inhibition/switching task (Stroop Interference), which was considered to recruit the highest level of executive functioning (multiple executive processes), but no training effect was found for the naming (Neutral) or inhibition (Incongruent) conditions of the Stroop task. They therefore suggested that aerobic dancing selectively improves tasks assessing switching and not necessarily tasks requiring inhibitory processes. The researchers proposed that differences in the type of aerobic exercises performed (i.e. aerobic dancing, walking, running etc.) could explain the inconsistent findings across studies (27).

In contrast to the findings of the current study, a few investigators observed a beneficial effect of aerobic training on lower level cognitive processes. A meta-analytic review reported modest improvements in older adults' lower and higher level neurocognitive functions after participation in aerobic training interventions that lasted between six weeks and 18 months. These improvements were observed for attention and processing speed, executive function and memory; whereas working memory did not benefit from aerobic training (31). Additionally, Dustman *et al.* (8) found that four months of aerobic training resulted in significantly better scores on simple and complex cognitive tasks compared to strength and flexibility training.

As hypothesized, the HIIT group experienced the largest improvement in walking endurance compared to the other training groups. This is not an uncommon finding in the literature (13, 16). Helgerud *et al.* (13) found that healthy, trained men who exercised at higher intensities (90-95% HR_{max}) exhibited the biggest gains in aerobic capacity, whereas those exercising at lower intensities (70 and 85% HR_{max}) did not improve their VO_{2max}. This finding, as well as the results of the current study, supports the notion that cardiovascular adaptations to training (i.e. improvements in VO_{2max}) are intensity dependent (15).

A surprising finding was that the MCT group did not experience an improvement in walking endurance, while the RT group actually showed a greater, although not statistically significant, improvement in walking endurance compared to the MCT group. It is generally accepted that aerobic training leads to larger increases in aerobic capacity compared to resistance training (8, 30). However, there are results to the contrary. Some investigators observed no effect of RT on VO_{2max} (11), while others reported a beneficial effect on VO_{2max} and walking endurance (1, 25, 32).

Thus, the combination of higher exercise intensities and shorter exercise durations proved more effective in older adults than the traditional prolonged moderate exercise intensity training. The duration of the exercise sessions for both the HIIT and RT groups in this study was 30 minutes, compared to the 47 minutes of the MCT group. However, the shorter duration sessions were done at higher exercise intensities than the longer duration sessions.

Another key finding of this study was that the results do not fully support the proposed association between increased physical function and cognitive performance. The RT group showed a statistically significant improvement on the executive cognitive tasks beyond the 4-week test period, with the HIIT and MCT groups exhibiting a similar trend. In walking endurance a statistically significant improvement was only seen for the HIIT group (difference of -1.4 minutes; $P < 0.05$), whereas in ES-values a similar trend was seen for the RT group (difference of 0.7 minutes; $P > 0.05$). In contrast, the MCT group did not experience an increase in aerobic fitness, while their performance on the executive cognitive tasks showed a practically meaningful improvement from week 4 to post-test. These findings are in contrast to our anticipated hypothesis that greater gains in fitness will induce larger increases in cognitive performance.

The results exhibited by the MCT group are also inconsistent with the findings reported by Dustman *et al.* (8), where a pronounced increase in VO_{2max} and Stroop Interference was observed after 16 weeks of aerobic training. There may be two possible explanations for these conflicting findings: (a) differences in computing the Stroop Interference effect and (b) dissimilarities in the exercise protocols. Dustman *et al.* (8) subtracted the Stroop Word condition from the Incongruent condition, whereas the Interference score in the present study was calculated as the difference in reaction time between the Neutral and Incongruent conditions. The intensity reported in Dustman's study is higher than the exercise intensity used in the present study. It could be argued that our training stimulus was too low for the MCT group to induce statistically significant improvements in aerobic capacity and on this specific cognitive task.

As reported in Chapter 2, the increase in the RT group's muscle strength has been shown to positively correlate with changes in the participants' walking endurance; thus, providing an explanation for their performance improvement on the Bruce test. Beneficial effects of both resistance and aerobic training interventions on measures of functional mobility, including walking/gait speed (11, 21), Timed-Up-and Go performance (3, 26) and chair-rising time (14) have been previously reported.

CONCLUSION

Among the cognitive tests an improvement was seen in the complex tests beyond the 4-week period of training for the RT group (with a statistically significant improvement). This trend was also seen for the HIIT and MCT groups. Regarding physical fitness a statistically significant improvement was observed in the walking endurance test for the HIIT group, a clear trend which was also present for the RT group, but not to the same extent for the MCT group. The results of the present study emphasize the fact that older individuals should incorporate exercise programmes of shorter durations, but higher intensities, for optimal gains in cognitive and physical function.

IMPLICATIONS FOR FUTURE RESEARCH

This is the first study to examine the effect of HIIT on older individuals' cognitive function. Our findings highlight the importance of this mode of training, in addition to traditional aerobic and resistance training, for the promotion of health and wellbeing in the older population. Additional research is needed to verify our findings. Future studies should investigate the long-term effects of HIIT on older individuals' health and physical function. Interventions combining interval training with traditional training modes will be helpful to determine the best exercise prescription for healthy, older adults.

STUDY LIMITATIONS

The small sample size of each study group is a limitation to the present study. It cannot be excluded that there may be a large learning effect when Stroop tasks are repeated over a period of time. Even though the sequence of trials in each Stroop condition was randomized for every individual at each testing point, all the groups (including the CON group) showed an improvement in reaction time on the simple and complex cognitive tasks after the 16-week intervention period. To overcome the potential influence of the learning effect on the results, the sub-analysis over the period from 4 to 16 weeks was presented to reflect the true outcomes of exercise training.

REFERENCES

1. Ades PA, Ballor DL, Ashikaga T, Utton JL, Nair KS. Weight training improves walking endurance in healthy elderly persons. *Ann Intern Med*. 1996;124(6):568–72.
2. Anderson-Hanley C, Nimon JP, Westen SC. Cognitive health benefits of strengthening exercise for community-dwelling older adults. *J Clin Exp Neuropsychol*. 2010:32(9):996–1001.
3. Arnarson A, Geirsdottir OG, Ramel A, Briem K, Jonsson PV, Thorsdottir I. Effects of whey proteins and carbohydrates on the efficacy of resistance training in elderly people: double blind, randomised controlled trial. *Eur J Clin Nutr*. 2013;67(8):821–6.
4. Blumenthal JA, Emery CF, Madden DJ, *et al.* Cardiovascular and behavioral effects of aerobic exercise training in healthy older men and women. *J Gerontol A Biol Sci Med Sci*. 1989;44(5):M147–57.
5. Cassilhas RC, Viana VAR, Grassmann V, *et al.* The impact of resistance exercise on the cognitive function of the elderly. *Med Sci Sports Exerc*. 2007:39(8):1401–7.
6. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988. p. 273-406.
7. Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci*. 2003;14(2):125–30.
8. Dustman RE, Ruhling RO, Russell EM, *et al.* (1984). Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiol Aging*. 1984;5(1):35–42.
9. Etnier JL, Chang Y-K. (2009). The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. *J Sport Exerc Psychol*. 2009;31:469–83.
10. Fisk JE, Sharp CA. Age-related impairment in executive functioning: updating, inhibition, shifting, and access. *J Clin Exp Neuropsychol*. 2004;26(7):874–90.
11. Forte R, Boreham CAG, Leite JC, *et al.* Enhancing cognitive functioning in the elderly: multicomponent vs resistance training. *Clin Interv Aging*. 2013;8:19–27.
12. Foster C, Jackson AS, Pollock ML, *et al.* Generalized equations for predicting functional capacity from treadmill performance. *Am Heart J*. 1984;107(6):1229–34.
13. Helgerud J, Høydal K, Wang E, *et al.* Aerobic high-intensity intervals improve VO2max more than moderate training. *Med Sci Sports Exerc*. 2007;39(4):665–71.

14. Kalapotharakos VI, Michalopoulos M, Strimpakos N, Diamantopoulos K, Tokmakidis SP. Functional and neuromotor performance in older adults: effect of 12 wks of aerobic exercise. *Am J Phys Med Rehabil*. 2006;85(1):61–7.
15. Kemi OJ, Haram PM, Loennechen JP. Moderate vs high exercise intensity: differential effects on aerobic fitness, cardiomyocyte contractility, and endothelial function. *Cardiovasc Res*. 2005;67(1):161–72.
16. King J, Broeder C, Browder K, Panton L. A comparison of interval vs steady-state exercise on substrate utilization in overweight women. *Med Sci Sports Exerc*. 2002;34(5):S130.
17. Kramer AF, Hahn S, Cohen NJ, *et al.* Ageing, fitness and neurocognitive function. *Nature*. 1999;400(6743):418–9.
18. Lindwall M, Rennemark M, Berggren T. Movement in mind: the relationship of exercise with cognitive status for older adults in the Swedish National Study on Aging and Care (SNAC). *Aging Ment Health*. 2008;12(2):212–20.
19. Liu-Ambrose T, Donaldson MG, Ahamed Y, *et al.* Otago home-based strength and balance retraining improves executive functioning in older fallers: a randomized controlled trial. *J Am Geriatr Soc*. 2008;56(10):1821–30.
20. Liu-Ambrose T, Donaldson MG. Exercise and cognition in older adults: is there a role for resistance training programmes? *Br J Sports Med*. 2009;43(1):25–7.
21. Liu-Ambrose T, Nagamatsu LS, Graf P, Beattie BL, Ashe MC, Handy, TC. Resistance training and executive functions: a 12-month randomized controlled trial. *Arch Intern Med*. 2010;170(2):170–8.
22. Liu-Ambrose T, Nagamatsu LS, Voss MW, Khan KM, Handy TC. Resistance training and functional plasticity of the aging brain: a 12-month randomized controlled trial. *Neurobiol Aging*. 2012;33(8):1690–8.
23. McAuley E, Mullen SP, Hillman CH. Physical activity, cardiorespiratory fitness, and cognition across the lifespan. In: *Social Neuroscience and Public Health*. Springer; 2013 p. 235–52.
24. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cogn psychol*. 2000;41(1):49–100.
25. Parker ND, Hunter GR, Treuth MS, *et al.* Effects of strength training on cardiovascular responses during a submaximal walk and a weight-loaded walking test in older females. *J Cardiopulm Rehabil Prev*. 1996;16(1):56–62.

26. Pinto RS, Correa CS, Radaelli R, Cadore EL, Brown LE, Bottaro M. Short-term strength training improves muscle quality and functional capacity of elderly women. *AGE*. 2014;36(1):365–72.
27. Predovan D, Fraser SA, Renaud M, Bherer L. The effect of three months of aerobic training on Stroop performance in older adults. *J Aging Res*. 2012;2012:1–7.
28. Ratey JJ, Loehr JE. The positive impact of physical activity on cognition during adulthood: a review of underlying mechanisms, evidence and recommendations. *Rev Neurosci*. 2011;22(2):171–85.
29. Royall DR, Palmer R, Chiodo LK, Polk MJ. Declining executive control in normal aging predicts change in functional status: the Freedom House Study. *J Am Geriatr Soc*. 2004;52(3):346–52.
30. Smiley-Oyen AL, Lowry KA, Francois SJ, Kohut ML, Ekkekakis P. Exercise, fitness, and neurocognitive function in older adults: the “selective improvement” and “cardiovascular fitness” hypotheses. *Ann Behav Med*. 2008;36(3):280–91.
31. Smith PJ, Blumenthal JA, Hoffman BM, *et al.* Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. *Psychosom Med*. 2010;72(3):239–52.
32. Wieser M, Haber P. The effects of systematic resistance training in the elderly. *Int J Sports Med*. 2007;28(1):59–65.

Chapter 4: Article 3

Cerebral oxygenation during cortical activation: The differential influence of three exercise training modalities

Status: To be submitted to Medicine & Science in Sports & Exercise

Cerebral oxygenation during cortical activation: The differential influence of three exercise training modalities

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ABSTRACT

Background: The influence of exercise training on cerebral oxygenation patterns is inconsistent and not well understood. Physical training induces structural brain changes as well as functional changes in neural networks essential for cognitive processing. It is, however, uncertain how the changes relate to cognitive performance and it remains to be established if these patterns are training mode dependent.

Purpose: The primary aim of this study was to determine if the exercise training mode has a differential effect on older individuals' cerebral oxygenation during cortical activation.

Methods: Sixty seven inactive individuals (55 to 75 years) volunteered for this intervention study. Participants were allocated to a resistance training (RT) group (n=22), high-intensity interval training (HIIT) group (n=13), moderate continuous training (MCT) group (n=13) and a control (CON) group (n=19). Each training group performed three supervised exercise sessions per week for a period of 16 weeks. Near-infrared spectroscopy (NIRS) was used to measure cerebral oxygenation during a simple and complex cognitive task. Data were analysed using mixed model repeated measures ANOVA and $P < 0.05$ was considered statistically significant. Cohen's effect sizes were calculated to compare the magnitude of differences in outcome variables between the groups.

Results: CON showed higher relative O_2Hb values during the simple and complex Stroop tasks during post-test (ES = 0.76 and 0.62, respectively; $P < 0.05$). MCT showed a decrease in O_2Hb on the simple (ES = 0.48; $P > 0.05$) and complex (ES = 0.50; $P > 0.05$) tasks. The HIIT groups' O_2Hb on the simple task decreased from pre-test (ES = 0.45; $P > 0.05$). MCT showed an increase in HHb on the simple (ES = 0.89; $P < 0.05$) and complex (ES = 1.14; $P < 0.05$) cognitive tasks. HIIT exhibited a smaller decrease in the concentration of HHb compared to pre-test measurements on the simple (ES = 0.67; $P > 0.05$) and complex tasks

(ES = 0.49; $P > 0.05$). The RT group did not show any significant changes in their activation patterns during the simple or complex task when comparing pre- and post-test values (ES < 0.3; $P > 0.05$).

Conclusion: This study showed that 16 weeks of exercise training result in more efficient cerebral oxygenation during cortical activation compared to a no-exercise control group. High-intensity interval training and moderate continuous aerobic training proved to be superior to resistance training for task-efficient cerebral oxygenation and improved oxygen utilization during cortical activation in older individuals.

Key Words: NEAR-INFRARED SPECTROSCOPY, PREFRONTAL CORTEX, STROOP TASK, EXERCISE TRAINING

BACKGROUND

The ageing brain undergoes several structural and functional changes, including decreases in brain volume (27) and alterations in cerebral blood flow and metabolism (1, 3). Declines in older adults' cognitive processes, specifically executive cognitive control, also become evident with senescence (22). The existing literature indicates that physical exercise and increased levels of aerobic fitness may protect against the age-related declines in brain structure and function and the subsequent cognitive deterioration (1, 2, 5, 8, 13, 14, 32).

The effect of exercise training on cerebral oxygenation in the prefrontal cortex is not well understood. In their review on the effects of physical exercise on brain structure and function, Brehmer *et al.* (4) highlighted that changes in brain activation patterns following intervention studies are inconsistent. Results from the few published longitudinal studies indicate that aerobic (9) and resistance training (20) are linked to functional changes in neural networks underlying specific cognitive processes. Instances of increased (9, 20) and decreased (30) neural activation in the prefrontal cortex have been reported. Greater activation may be the result of engaging additional brain regions, while reduced activation could indicate an improvement in task-efficiency (31). Hoshi & Tamura (17) observed less change in the haemoglobin oxygenation state of subjects who had no difficulty solving a problem, suggesting that an easy task would require less neuronal activation. Furthermore, instances of enhanced activation in older compared to younger adults have been proposed as a compensatory mechanism for the declines in brain structure and function that become evident with senescence (26).

The majority of research studies investigating the influence of exercise training on changes in older individuals' brain activation and oxygenation patterns are cross-sectional (12, 33). Consequently, no inferences regarding causation can be made. Nevertheless, it has been suggested that cardiovascular training can result in activation patterns that resemble similar trends as the younger, more efficient brains (16, 30). Longitudinal studies on the influence of other exercise modalities on the pattern of prefrontal oxygenation (i.e. changes in neural recruitment) during tasks that require cortical activation will expand the existing knowledge in this field.

One previous intervention study compared the effects of cardiovascular and coordination training on older adults' physical and cognitive performance (30). The researchers found that both training types resulted in enhanced cognitive performance and decreased task-related activation in the prefrontal areas when performing an executive control task. It was suggested that the alterations in brain activation post training are indicative of more efficient processing. This study provided the first evidence that the exercise-related changes in brain activation patterns are not limited to aerobic training. However, it is still unknown how other training modalities will compare.

The influence of resistance training (RT) and high-intensity interval training (HIIT) on cerebral oxygenation and cognitive function have not been investigated before. Misconceptions about the use of RT and HIIT in the older population could possibly explain the lack of studies exploring this mode of exercise. Methodological constraints such as the use of dissimilar imaging modalities to measure brain activation and variant cognitive tests to elicit activation changes make it difficult to compare the results across studies, and ultimately determine if the type of exercise plays a role in the brain oxygenation response. To date, no study has compared the effects of three different training modalities on older adults' cerebral oxygenation while performing a task that produces cortical activation.

Thus, the primary aim of this study was to determine if the exercise training mode has a differential effect on older individuals' cerebral oxygenation during cortical activation.

METHODS

Participants

Inactive men and women between 55 and 75 years volunteered to take part in this study. Participants were screened to rule out the possibility of any signs and/or symptoms of cardiovascular, pulmonary or metabolic diseases. The Montreal Cognitive Assessment (MoCA) was used to identify participants with cognitive dysfunction. Individuals were included if they: (a) had a body mass index (BMI) of less than 35 kg/m^2; and (b) had not been participating in at least 30 minutes of moderate intensity physical activity (64%-76% of maximal heart rate) on at least three days of the week for the previous three months. All the participants were informed of the purpose of the study and gave their written consent to participate. The study proposal was approved by the Ethics Committee of Stellenbosch University (HS891/2013).

Of the 82 volunteers who were screened, 72 participants were eligible to participate in the study. They were assigned to one of three training interventions, namely resistance training (RT), high-intensity interval training (HIIT) and moderate continuous training (MCT), or a no-exercise control (CON) group by means of a randomised block design. Five participants dropped out before the start of the intervention, while two participants dropped out of the HIIT group during the course of the study. Therefore, 67 men and women (mean age 62.7 ± 5.7 years; BMI 26.4 ± 4.0 kg/m²) completed the study, with 22 participants in the RT group (male/female ratio: 7/15), 13 in the HIIT group (male/female ratio: 3/10), 13 in the MCT group (male/female ratio: 3/10) and 19 in the CON group (male/female ratio: 8/11).

Testing protocol

Anthropometric measurements included stature and body mass, in order to determine each participant's body mass index (BMI). All the cognitive and cerebral oxygenation measurements were performed with the participant seated in front of a computer screen. Two conditions of the Stroop task were completed, giving an indication of the participant's information processing speed and executive cognitive control, respectively. During the simple task (Stroop Neutral) participants were instructed to identify the colour of a rectangle with the choices written in black ink. The next, more complex task, Stroop Incongruent, required participants to identify the ink colour of a word written in incongruent coloured ink (e.g. the word "blue" printed in red ink), with the choices written in black ink. All participants responded with the right hand.

Changes in oxy-haemoglobin (O_2Hb) and deoxy-haemoglobin (HHb), and the total haemoglobin index (THI) were measured by a two-channel near-infrared spectrometer (*NIRO 200NX*, Hamamatsu, Japan) during completion of the Stroop task. Measurements were made at wavelengths of 735 nm, 810 nm, and 850 nm as determined by the manufacturer, with the sampling time set at five hertz (Hz). The location of the measurement probes was calculated using the international 10-20 system for EEG electrode placement (19). The light emitter sensor was placed on the medial side of the forehead for the prefrontal cortex measurements, at Fp1 and Fp2 for the left and right side respectively, with the detectors being placed between positions F3 and F7 on the left side, and F4 and F8 on the right side. The distance between each emitter and detector was 4 cm. Before the cognitive tests were performed, the participants were instructed to sit quietly for five minutes while resting values were obtained. With Near-infrared spectroscopy (NIRS), it is not possible to measure optical path lengths and, subsequently, quantify absolute concentrations (11). Therefore, relative changes in O_2Hb, HHb and THI compared to baseline were used for statistical analysis. The concentration of O_2Hb represents the balance between oxygen delivery and oxygen utilization, HHb reflects oxygen extraction by the tissue and THI is a measure of the total haemoglobin content within tissue, thus providing an indication of cerebral blood volume.

Training programmes

Participants trained three times per week over a period of 16 weeks under supervision. The RT programme consisted of three sets of 10 repetitions of seven different upper and lower body resistance exercises. The intensity progressively increased from the first to the third set. Initially, loads of 50%, 75% and 100% of the 10 repetition maximum (RM) were performed. After eight weeks the load for each set was increased to 75%, 85% and 100% of the individual's 10RM, respectively.

The MCT group performed continuous walking on a treadmill at 70 – 75% of maximal heart rate (HRmax) for 47 minutes. The HIIT group performed four intervals of four minutes treadmill walking at 90 – 95% HRmax, followed by three minute active recovery periods at

70% HRmax. The duration of each RT and HIIT session was approximately 30 minutes, excluding the warm-up and cool down.

STATISTICAL ANALYSIS

Statistical analysis was performed using STATISTICA 12. Normal probability plots were inspected to assess the normality of the data and check for outliers, and were mostly found to be in order.

Mixed model repeated measures ANOVA was done to test the effects of the intervention on the various outcome measurements. In the analysis, GROUP and TIME were treated as fixed effects with the participants as random effects. Results were considered statistically significant if $P < 0.05$. Cohen's effect sizes (ES) were calculated to compare the magnitude of differences in outcome variables between the experimental groups. Cohen's thresholds of 0.2, 0.5, 0.8 and 1.2 were interpreted as small, moderate, large and very large effects, respectively (7). Descriptive statistics are reported as means $\pm$ SD.

The mean haemodynamic values obtained at baseline were subtracted from the mean values attained during the simple and complex Stroop tasks, respectively. Additionally, the haemodynamic changes during the simple task were subtracted from the complex task to give an indication of the Stroop interference effect. Baseline haemodynamic values refer to values obtained during the rest period at the given testing session (pre-test and post-test). Pre-test values refer to the measurements obtained during the first testing session. Haemodynamic changes in the left prefrontal cortex were used for all analyses.

RESULTS

There were no statistically significant differences in the pre-test characteristics of the groups ($P > 0.05$) (Table 1).

TABLE 1. Descriptive characteristics of the participants (mean ± SD).

Variable	HIIT group	MCT group	RT group	CON group
N	13	13	22	19
Age (years)	64.5 ± 6.3	61.6 ± 5.8	62.4 ± 5.1	62.5 ± 5.6
Height (cm)	166 ± 8.9	163.5 ± 8.6	167.8 ± 7.8	168.7 ± 7.9
Body mass (kg)	73.8 ± 13.7	71.0 ± 14.4	73.3 ± 15.5	76.8 ± 13.7
BMI ($kg \cdot m^{-2}$)	26.6 ± 4.0	26.5 ± 4.2	25.8 ± 4.0	26.9 ± 3.7
MoCA score	27.9 ± 1.5	27.6 ± 1.3	27.5 ± 1.3	28.2 ± 1.6

No statistically significant differences in the physical characteristics of the groups at pre-test ($P > 0.05$).

HIIT, high-intensity interval training; MCT, moderate continuous training; RT, resistance training; CON, control; BMI, body mass index; MoCA, Montreal Cognitive Assessment.

Behavioural results

Stroop reaction time

The GROUP x TIME interaction effects for the Neutral and Incongruent Stroop conditions were not statistically significant, however a significant TIME effect was evident at post-test for both Stroop conditions ($P < 0.001$) (Table 2).

TABLE 2. Absolute values for Stroop reaction time for all the groups (mean ± SD).

	HIIT		**MCT**		**RT**		**CON**	
	Reaction time (sec)							
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Neutral condition	31.2 ± 5.0	25.8 ± 2.3	26.3 ± 2.3	24.6 ± 2.2	30.0 ± 5.2	25.5 ± 3.6	28.9 ± 5.0	25.7 ± 3.9
Incongruent condition	55.6 ± 14.1	37.7 ± 6.7	53.1 ± 5.2	36.9 ± 5.3	53.6 ± 17.5	38.9 ± 6.8	49.9 ± 16.8	37.5 ± 8.3

A significant TIME effect was evident for the simple and complex tasks after the 16-week intervention period ($P < 0.001$).

HIIT, high-intensity interval training; MCT, moderate continuous training; RT, resistance training; CON, control.

Haemodynamic results

Brain activation (O_2Hb and HHb)

At pre-test, all groups showed an increase in brain activity [as illustrated by an increase in oxy-haemoglobin (O_2Hb) and a decrease in deoxy-haemoglobin (HHb)] during the simple and complex Stroop task. The same trend was evident at the post-test (Fig. 1). At pre-test there were no between-group differences in relative O_2Hb and HHb concentration changes on either Stroop task. Within-group analysis indicated that the control (CON) group had statistically significantly higher relative O_2Hb values during the simple and complex Stroop tasks at post-test compared to their pre-test values (ES = 0.76 and 0.62, respectively; $P < 0.05$) (Fig. 1A and 1C). The CON group's post-test values were also statistically significantly higher than the values of the high-intensity interval training (HIIT), moderate continuous training (MCT) and resistance training (RT) groups on both the simple (ES = 1.40, 1.54 and 0.71, respectively) and complex (ES = 1.26, 1.53 and 0.71, respectively; $P < 0.05$) Stroop tasks.

There was a statistically significant difference in post-test O_2Hb on the simple task between the RT and MCT groups (ES = 0.93; $P < 0.05$). Overall, a statistically significant GROUP effect was found for the relative O_2Hb values on the simple and complex tasks ($P < 0.05$). After the 16-week training period, the MCT and HIIT groups generally demonstrated lower levels of cortical activation compared to pre-test values on both Stroop tasks (simple and complex). Each condition induced a smaller increase in O_2Hb and a smaller decrease in HHb (Fig. 1), although only with a statistically significant difference for MCT regarding the HHb values. No statistically significant difference was seen for any of these two groups between the pre- and post-test regarding O_2Hb values, and for the HIIT group regarding the HHb values. Compared to the pre-test, the MCT group showed a moderate decrease in O_2Hb on the simple (ES = 0.48; $P > 0.05$) and complex (ES = 0.50; $P > 0.05$) tasks. The HIIT groups' O_2Hb on the simple task decreased from pre-test (ES = 0.45; $P > 0.05$), while their change in O_2Hb on the complex task was of similar magnitude than at pre-test (ES = 0.09; $P > 0.05$). The RT group did not show any significant changes in their activation patterns on the simple or complex task when comparing pre- and post-test values (ES < 0.3; $P > 0.05$).

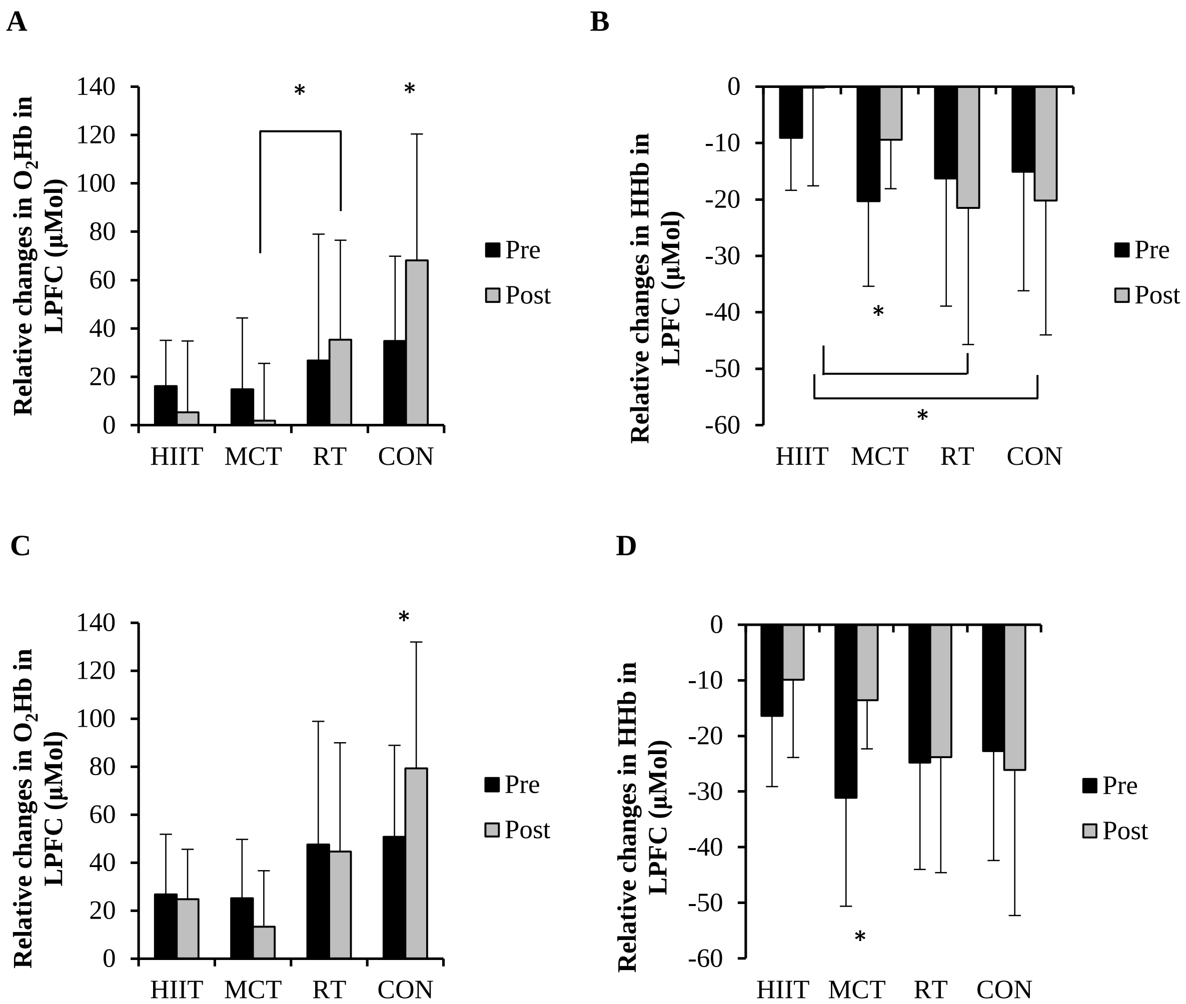

FIGURE 1 – (A) Relative changes in O_2Hb in the left prefrontal cortex (LPFC) during the simple cognitive task. *The CON group showed significantly higher levels of O_2Hb at post-test compared to pre-test levels ($P < 0.05$). **(B) Relative changes in HHb in the LPFC during the simple cognitive task.** *The MCT group showed an increase in HHb compared to pre-test ($P < 0.05$). **(C) Relative changes in O_2Hb in the LPFC during the complex cognitive task.** *The CON group showed significantly higher levels of O_2Hb at post-test compared to pre-test levels ($P < 0.05$). **(D) Relative changes in HHb in the LPFC during the complex cognitive task.** *The MCT group showed an increase in HHb compared to pre-test ($P < 0.05$).

At post-test, the RT and CON groups showed a significantly greater decrease in HHb during the simple task than the HIIT group who exhibited a very small relative change (ES = 0.95 and 0.91, respectively; $P < 0.05$) (Fig 1B). Compared to pre-test, the MCT group showed a large practically and statistically significant increase in HHb on the simple (ES = 0.89; $P < 0.05$) (Fig. 1B) and complex (ES = 1.14; $P < 0.05$) (Fig. 1D) cognitive tasks. The HIIT group also exhibited a smaller decrease in the concentration of HHb compared to pre-test measurements on the simple (ES = 0.67; $P > 0.05$) and complex tasks (ES = 0.49; $P > 0.05$).

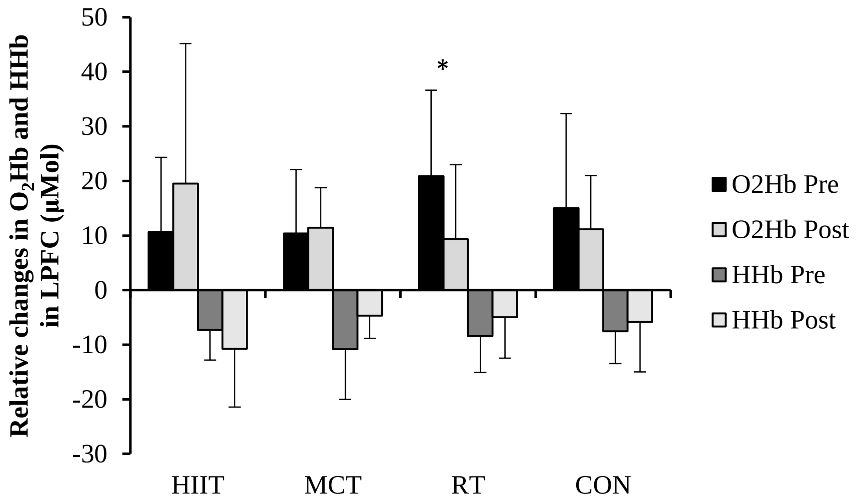

FIGURE 2 - Relative changes in O_2Hb and HHb in the left prefrontal cortex (LPFC) when task complexity increased (Interference effect). *The RT group showed a decreased level of O_2Hb compared to pre-test ($P < 0.05$).

There was a statistically significant GROUP x TIME interaction for the relative change in O_2Hb with increased task difficulty (Interference effect) ($P < 0.05$). The change in HHb from the simple to the complex task was not statistically significant from pre- to post-test in any group ($P > 0.05$) (Fig. 2). The RT group showed a significant decrease in the magnitude of change in O_2Hb after the intervention period (ES = 0.79; $P < 0.05$), accompanied by a moderately practically significant increase in HHb (ES = 0.49; $P > 0.05$). In contrast, the HIIT group showed a trend towards an increased activation from the simple to the more complex task after the intervention period, evident from the increase in O_2Hb (ES = 0.44; $P >$

0.05) and decrease in HHb (ES = 0.44; $P > 0.05$). When the level of task difficulty increased, changes in the MCT group's O_2Hb was similar at pre- and post-test (ES = 0.11; $P > 0.05$), however a large practical significant increase in HHb was observed (ES = 0.84; $P = 0.06$).

Blood volume (THI)

At pre-test there were no between-group differences in the total haemoglobin index (THI) on either Stroop task (Fig. 3).

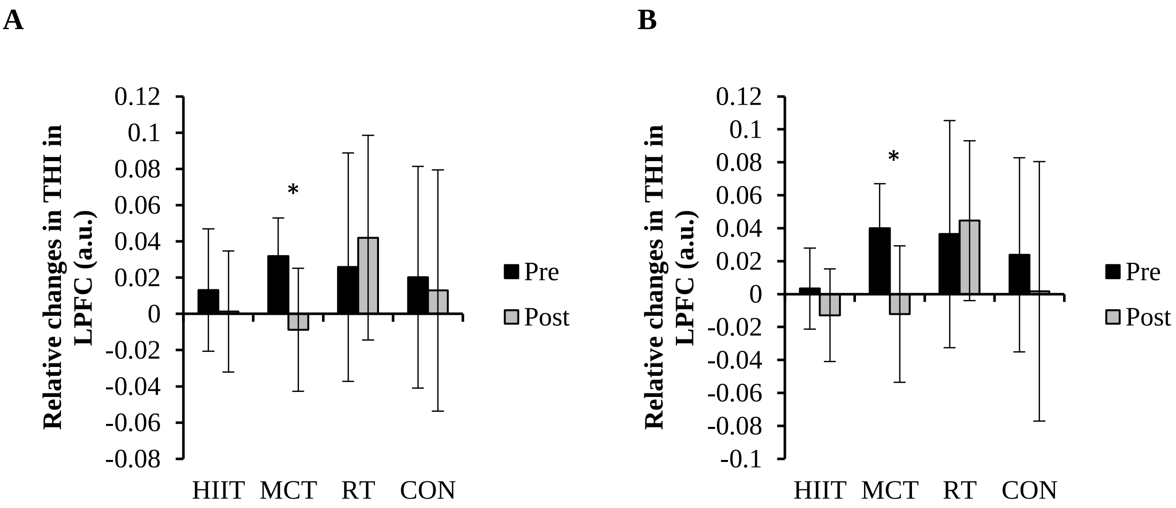

FIGURE 3 – (A) Relative changes in THI in the left prefrontal cortex (LPFC) during the simple cognitive task. *The MCT group showed a decrease in THI from pre- to post-test ($P < 0.05$). **(B) Relative changes in THI in the LPFC during the complex cognitive task.** *The MCT group showed a decrease in THI from pre- to post-test ($P < 0.05$).

Small changes in THI were observed during the simple task in the CON, RT and HIIT groups, whereas the MCT group showed a large decrease in THI (ES = 1.42; $P < 0.05$) (Fig. 3A). At post-test the CON (ES = 0.32; $P > 0.05$), HIIT (ES = 0.62; $P > 0.05$) and MCT (ES = 1.49; $P < 0.05$) groups displayed a decrease in THI (compared to pre-test) during the complex task, while the RT group exhibited a slight increase (ES = 0.14; $P > 0.05$) (Fig. 3B). There was a statistically significant GROUP effect for the complex task ($P < 0.05$).

The change in THI from the simple to the complex task revealed a statistically significant TIME effect ($P < 0.05$) (Fig. 4). There was a statistically significant reduction in THI of the RT group from the simple to the complex task (ES = 0.82; $P < 0.05$). An increase was observed at pre-test, whereas post-test values showed a decrease. Pre-post comparisons also revealed a large practical and statistically significant decrease in the MCT group's THI when task complexity increased (ES = 0.95; $P < 0.05$).

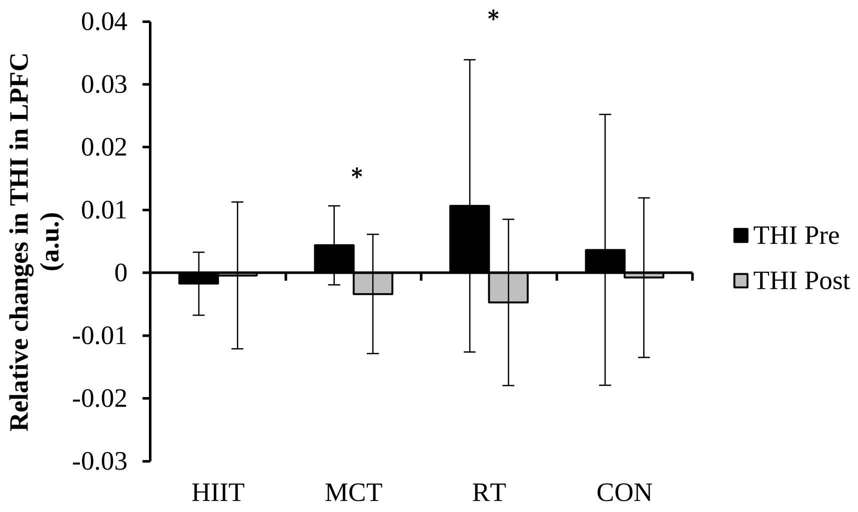

FIGURE 4 - Relative changes in THI in the left prefrontal cortex (LPFC) when task complexity increased (Interference effect). *The MCT and RT groups showed a decreased level of THI compared to pre-test ($P < 0.05$).

DISCUSSION

The main findings of the study are that: (a) 16 weeks of exercise training result in more efficient cerebral oxygenation during cortical activation compared to a no-exercise control group; (b) High-intensity interval training and moderate continuous aerobic training are superior to resistance training for task-efficient cerebral oxygenation and improved oxygen utilization during cortical activation in older individuals.

Brain oxygenation increased in all the groups when the cognitive task demand increased, indicating that cortical activation was a function of task difficulty. Whereas participants in the training groups improved their performance on the cognitive test without a concomitant increase in brain activation, the improvements in cognitive performance in the CON group were accompanied by significantly greater levels of cortical activation (higher concentrations of O_2Hb) during both the simple and more complex Stroop tasks. This finding suggests that their brain function was less efficient and they had to compensate by over-activation of the neural circuitry. The latter can be localized in the same neural network, or it could be more widespread (25). Reuter-Lorenz & Park (26) also stated that higher activation in the prefrontal regions could reflect compensation for insufficient processing in other brain regions. This observation may also provide further support for the compensation-related utilization of neural circuits hypothesis (CRUNCH), which states that increases in cerebral activation serve as a compensatory mechanism in order to avoid performance declines (25).

Research indicates that chronological age is influential in the pattern of neuronal activation. Enhanced activation in older compared to younger adults is a proposed compensatory mechanism for the declines in brain structure and function that become evident with senescence (26). Older adults will therefore recruit more neuronal resources to perform at an equal level than their younger counterparts (25). Thus, overactivation to achieve higher cognitive performance levels may be disadvantageous for the older individual.

The CRUNCH hypothesis posits that the compensation is only effective for lower level cognitive tasks, whereas a further increase in task demand is accompanied by insufficient neural processing and a decline in activation (25). Both before and after the intervention, all the groups showed an increase in brain activation when task difficulty increased. This trend can be considered contradictory to the assumption of the CRUNCH model. However, it appears that the magnitude of the activation response during the lower level cognitive task affects the subsequent amount of activation when the task demand increases.

In this study, only the HIIT group exhibited a trend towards higher cortical activation when shifting from the simple to complex task after the training intervention. The MCT and CON groups showed a similar activation pattern at pre- and post-test, while the RT group showed a decreased activation at post-test. This differential pattern of change in O_2Hb from the simple to complex cognitive task in response to training possibly relates to the amount of cognitive reserve used during a simple cognitive demand. If there is a greater need to rely on cognitive reserve during a simple task, it may lead to an inability to activate additional neural networks when task demand increases (25). The RT group already exhibited high levels of O_2Hb during the simple cognitive task after the intervention; therefore one can speculate whether additional activation of the neuronal resources may have been limited when they performed the more challenging cognitive task. In contrast, the HIIT group showed minimal change in O_2Hb during the simple task and one can speculate whether they were thus able to activate more neuronal resources during the more complex cognitive task.

Secondly, the findings of the current study suggest that aerobic training modalities result in better oxygen utilization and improved task-efficiency in the prefrontal cortex during cognitive demanding tasks. Both HIIT and MCT proved to be superior compared to RT for the promotion of task-efficient cerebral oxygenation during cortical activation.

After the training period the HIIT and MCT groups showed a trend indicating decreased brain activation with decreased O_2Hb on the simple task compared to their pre-test activation patterns. This activation was, however, still slightly higher than baseline values. The changes for O_2Hb were not statistically significant for any of the two aerobic training groups. Furthermore, only the latter training groups showed an increased HHb in comparison to their pre-test values, although being statistically significant only for the MCT group. Thus, it is proposed that task-efficient cerebral oxygenation in the frontal lobes improved with aerobic training over the course of the intervention period.

Since the functional activity of the brain is related to the blood supply (31), enhanced neuronal activation will require increases in cerebral blood flow and metabolism (10). In addition, Mehagnoul-Schipper *et al.* (23) reported simultaneous increases in blood volume and cerebral oxygenation during cognitive activation in older adults. It is thus hypothesized that with exercise training, less cortical activation is required during a cognitive task, which will lead to a reduced blood volume and a subsequent reduction in blood flow to the prefrontal cortex. However, the slower blood flow rate through the prefrontal cortex allows for greater oxygen extraction by the tissue improving oxygen utilization.

This hypothesis is supported by the findings of this study. After the 16-week training period, the MCT group showed patterns indicating a reduction in their brain activation response during both Stroop tasks compared to pre-training levels. This group also showed a decrease in blood volume on each Stroop task, as well as when shifting from the simple to the complex task. In addition, they showed a concomitant increase in oxygen utilization, evident from increases in HHb concentrations, after the intervention period. The latter finding was also demonstrated by the HIIT group, who exhibited patterns indicating a reduced amount of activation and a decreased blood volume during the cognitive tasks after the training period. However, the changes for the HIIT group were not statistically significant.

Even though THI is a measure of blood volume, it could also give an indication regarding blood flow (24). Thus, the decreases in the THI of both the HIIT and MCT groups could indicate a reduction in cerebral blood flow in the prefrontal region which can be associated with the decreased neuronal activation. Consequently, there will be more time for oxygen to be extracted as a neural substrate. In contrast, when THI and brain activation is higher, blood will flow at a higher velocity to meet the demand of the increased neural activity, leaving less time for oxygen extraction. This hypothesis can serve as a plausible explanation for the difference in the activation patterns between the aerobic training groups (HIIT and MCT) and the RT group on the simple and complex Stroop tasks.

Our aforementioned hypothesis could also provide support for the changes in the RT group's brain oxygenation response when the task demand increased, after the training period. The RT group showed a significant decrease in THI from the simple to complex task, which could be linked to their decline in activation when task difficulty increased. Therefore, the reduction in blood flow rate at post-test resulted in greater oxygen extraction time compared to pre-test.

To the best of our knowledge, no previous longitudinal study used NIRS to investigate the exercise training effects on brain oxygenation in older individuals. Functional magnetic resonance imaging (fMRI) and NIRS have been shown to detect similar changes in cerebral oxygenation during brain activation in older individuals (23). The former method has been used in previous studies to determine training effects on brain activation (9, 20, 30). Voelcker-Rehage *et al.* (30) found that 12 months of aerobic training and coordination training resulted in decreased task-related activation in the prefrontal areas during the Flanker task, assessing cognitive inhibition. Comparable to the findings in this study, their control participants exhibited an increase in prefrontal activation.

Since the mechanisms responsible for the changes in brain oxygenation were not investigated in this study, it can only be speculated which physiological adaptations might have played a mediating role. Exercise training induces angiogenesis, neurogenesis and synaptogenesis via alterations in molecular mechanisms including changes in brain-derived neurotrophic factor (BDNF), vascular endothelial growth factor (VEGF) and increases in the production of insulin-like growth factor 1 (IGF-1) (15). Thus, the decreased activation and improved oxygen extraction observed in the aerobic training groups in this study could be the result of an increase in capillary density and subsequent slower blood flow rates and shorter diffusion distances in the prefrontal cortex.

There are suggestions in the literature that there is a relationship between brain activation levels, cognitive performance and aerobic fitness. For instance, Dupuy *et al.* (12) found that women with higher aerobic fitness levels (VO_{2max}) exhibited a greater cerebral oxygenation response and improved cognitive performance during the Stroop task compared to women with lower fitness levels. An increased blood volume was reported in the higher fit group, but no differences were evident in oxygen extraction between the study groups. The results of the current study, however, do not support these findings. Walking endurance during a modified Bruce treadmill test was used as a measure of aerobic fitness (Article 2). We found that there were greater improvements in the aerobic fitness levels of the HIIT (pre-post increase of 1.4 ± 1.3 min; ES = 0.91; $P < 0.05$) group and the RT group (pre-post increase of 0.7 ± 0.9 min; ES = 0.48; $P > 0.05$) compared to the MCT group (pre-post increase of 0.6 ± 1.0 min; ES = 0.16; $P > 0.05$), as depicted in Fig. 3A of the second article in this thesis. Both aerobic training groups showed a decrease in brain activation and trends of improvements in cognitive performance between 4-16 weeks of training. Thus, aerobic fitness is not necessarily a requirement for enhanced cognitive function. This finding is in agreement with the view of Smiley-Oyen *et al.* (29) who also suggested that an increase in aerobic fitness is not a prerequisite for improvements in executive cognitive control. The researchers also stated that the upregulation of biological mediators, i.e. BDNF and IGF-1 does not seem to be dependent on aerobic fitness. Thus, aerobic fitness level might not be the sole determinant of task-efficient brain oxygenation and activation patterns. Other mediators, such as training mode, could also be decisive.

A possible explanation for the uncertainty about the role of aerobic fitness levels in cognitive function relates to the nature of research study designs. An association of higher brain activation levels with improved performance can be evident in studies using cross-sectional designs (e.g., Ref. [12]), because individuals are not necessarily accustomed to the task (21). The pattern of activation, however, changes over the course of a longer period, i.e. in studies using longitudinal designs. Therefore, comparing results between cross-sectional and longitudinal studies should be done with caution.

It was suggested that different modes of exercise training might affect different neuro-cognitive networks (18). Aerobic training is linked to elevated levels of BDNF (28), while resistance training produces increased levels of IGF-1 (6). Thus: different mechanisms are triggered depending on the type of exercise. These dissimilarities could possibly explain the differential influences of exercise training mode on brain activation patterns observed in the present study. We suggest that especially our aerobic training groups experienced exercise-induced changes in brain structure and/or function that enabled them to exhibit more efficient brain oxygenation during cortical activation compared to a no-exercise CON group.

CONCLUSION

This study showed that 16 weeks of exercise training result in more efficient cerebral oxygenation during cortical activation compared to a no-exercise control group. High-intensity interval training and moderate continuous aerobic training proved to be superior to resistance training for task-efficient cerebral oxygenation and improved oxygen utilization during cortical activation in older individuals.

STUDY LIMITATIONS

The measurement of cerebral oxygenation in the present study was limited to a two-channel NIR spectrometer, thus prefrontal brain oxygenation. The possibility that activation changes occurred in other brain regions during the Stroop task can therefore not be excluded.

REFERENCES

1. Ainslie PN, Cotter JD, George KP, *et al.* Elevation in cerebral blood flow velocity with aerobic fitness throughout healthy human ageing. *J Physiol*. 2008;586(16):4005–10.
2. Bailey DM, Marley CJ, Brugniaux JV, *et al.* Elevated aerobic fitness sustained throughout the adult lifespan is associated with improved cerebral hemodynamics. *Stroke*. 2013;44(11):3235–8.
3. Bherer L, Erickson KI, Liu-Ambrose T. A review of the effects of physical activity and exercise on cognitive and brain functions in older adults. *J Aging Res*. 2013;2013:1–8.
4. Brehmer Y, Kalpouzos G, Wenger E, Lövdén M. Plasticity of brain and cognition in older adults. *Psychol Res*. 2014;78(6):790–802.
5. Brown AD, McMorris CA, Longman RS, *et al.* Effects of cardiorespiratory fitness and cerebral blood flow on cognitive outcomes in older women. *Neurobiol Aging*. 2010;31(12):2047–57.
6. Cassilhas RC, Viana VAR, Grassmann V, *et al.* The impact of resistance exercise on the cognitive function of the elderly. *Med Sci Sports Exerc*. 2007;39(8):1401–7.
7. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988. p. 273-406.
8. Colcombe SJ, Erickson KI, Scalf PE, *et al.* Aerobic exercise training increases brain volume in aging humans. *J Gerontol A Biol Sci Med Sci*. 2006;61(11):1166–70.
9. Colcombe SJ, Kramer AF, Erickson KI, *et al.* Cardiovascular fitness, cortical plasticity, and aging. *Proc Natl Acad Sci USA*. 2004;101(9):3316–21.
10. Davenport MH, Hogan DB, Eskes GA, Longman RS, Poulin MJ. Cerebrovascular reserve: the link between fitness and cognitive function? *Exerc Sport Sci Rev*. 2012;40(3):153–8.
11. Delpy DT, Cope M. Quantification in tissue near-infrared spectroscopy. *Phil Trans R Soc Lond B*. 1997;352:649–59.
12. Dupuy O, Gauthier CJ, Fraser SA, *et al.* Higher levels of cardiovascular fitness are associated with better executive function and prefrontal oxygenation in younger and older women. *Front Hum Neurosci*. 2015;9(66):1–12.
13. Erickson KI, Voss MW, Prakash RS, *et al.* Exercise training increases size of hippocampus and improves memory. *Proc Natl Acad Sci USA*. 2011;108(7):3017–22.
14. Foster PP, Rosenblatt KP, Kuljiš RO. Exercise-induced cognitive plasticity, implications for mild cognitive impairment and Alzheimer's disease. *Front Neurol*. 2011;2(28):1–15.

15. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci*. 2008;9(1):58–65.
16. Hollmann W, Strüder HK, Tagarakis CVM, King G. Physical activity and the elderly. *Eur J Cardiovasc Prev Rehabil*. 2007;14(6):730–9.
17. Hoshi Y, Tamura M. Detection of dynamic changes in cerebral oxygenation coupled to neuronal function during mental work in man. *Neurosci Lett*. 1993;150(1):5–8.
18. Hötting K, Röder B. Beneficial effects of physical exercise on neuroplasticity and cognition. *Neurosci Biobehav Rev*. 2013;37(9):2243–57.
19. Jurcak V, Tsuzuki D, Dan I. 10/20, 10/10, and 10/5 systems revisited: their validity as relative head-surface-based positioning systems. *Neuroimage*. 2007;34(4):1600–11.
20. Liu-Ambrose T, Nagamatsu LS, Voss MW, Khan KM, Handy TC. Resistance training and functional plasticity of the aging brain: a 12-month randomized controlled trial. *Neurobiol Aging*. 2012;33(8):1690–8.
21. Lustig C, Shah P, Seidler R, Reuter-Lorenz PA. Aging, training, and the brain: a review and future directions. *Neuropsychol Rev*. 2009;19(4):504–22.
22. McAuley E, Mullen SP, Hillman CH. Physical activity, cardiorespiratory fitness, and cognition across the lifespan. In: *Social Neuroscience and Public Health*. Springer; 2013 p. 235–52.
23. Mehagnoul-Schipper DJ, van der Kallen BFW, Colier WNJM, *et al.* Simultaneous measurement of cerebral oxygenation changes during brain activation by near-infrared spectroscopy and functional magnetic resonance imaging in healthy young and elderly subjects. *Hum Brain Mapping*. 2002;16(1):14–23.
24. Perrey S. Non-invasive NIR spectroscopy of human brain function during exercise. *Methods*. 2008;45(4):289–99.
25. Reuter-Lorenz PA, Cappell KA. Neurocognitive aging and the compensation hypothesis. *Curr Dir Psychol Sci*. 2008;17(3):177–82.
26. Reuter-Lorenz PA, Park DC. Human neuroscience and the aging mind: a new look at old problems. *J Gerontol B Psychol Sci Soc Sci*. 2010;65(4):405–15.
27. Scahill RI, Frost C, Jenkins R, Whitwell JL, Rossor MN, Fox NC. A longitudinal study of brain volume changes in normal aging using serial registered magnetic resonance imaging. *Arch Neurol*. 2003;60(7):989–94.
28. Seifert T, Brassard P, Wissenberg M, *et al.* Endurance training enhances BDNF release from the human brain. *Am J Physiol Regul Integr Comp Physiol*. 2010;298(2):R372–7.

29. Smiley-Oyen AL, Lowry KA, Francois SJ, Kohut ML, Ekkekakis P. Exercise, fitness, and neurocognitive function in older adults: the "selective improvement" and "cardiovascular fitness" hypothesis. *Ann Behav Med*. 2008;36(3):280–91.
30. Voelcker-Rehage C, Godde B, Staudinger UM. Cardiovascular and coordination training differentially improve cognitive performance and neural processing in older adults. *Front Hum Neurosci*. 2011;5(26):1–12.
31. Voelcker-Rehage C, Niemann C. Structural and functional brain changes related to different types of physical activity across the life span. *Neurosci Biobehav Rev*. 2013;37(9):2268–95.
32. Voss MW, Heo S, Prakash RS, *et al*. The influence of aerobic fitness on cerebral white matter integrity and cognitive function in older adults: results of a one-year exercise intervention. *Hum Brain Mapp*. 2013;34(11):2972–85.
33. Xu X, Jerskey, BA, Cote DM, *et al*. Cerebrovascular perfusion among older adults is moderated by strength training and gender. *Neurosci Lett*. 2014;560:26–30.

Chapter 5: General discussion

The main objective of this thesis was to compare the effects of resistance training (RT), high-intensity interval training (HIIT) and moderate continuous training (MCT) on aspects of older individuals' physical function, cognitive function and cerebral oxygenation. This research study was extended after the initial intervention period and two additional training modes (HIIT and MCT) were added to the project as independent variables. Due to this development the second chapter (Article 1) focuses exclusively on RT.

The importance of this study lies in the fact that RT is not a regular training mode of choice in older individuals, despite the known benefits of gains in skeletal muscle mass and strength. There is also a scarcity of longitudinal studies looking simultaneously at changes in muscle strength and physical function. The positive findings of this study warranted further investigation into the effects of RT on cognitive function and the comparison of RT to more aerobic type exercise.

In the following sections we will discuss our findings with regards to the effect of exercise training on (a) muscular and physical function, (b) cognitive function and (c) cerebral oxygenation; which constitute the main themes of this thesis.

A Exercise training effects on muscular and physical function in older adults

1. Muscle strength adaptations

There is consensus in the literature that RT leads to significant muscle strength gains in the older population (29, 34). In general, older individuals are mindful of the health benefits associated with RT. However, there are still a number of positive effects which are not well recognized (21).

The findings reported in the first article reaffirm the importance of RT for the older population and emphasize the fact that basic strength exercises can induce substantial muscle strength gains. Our RT intervention produced similar results compared to previous studies using more traditional programme designs (29, 34, 39). In the present study three sets of varying intensities were performed for each resistance exercise, with the first set being the easiest. The progression in the intensity seemed ideal for our study population, as we included older people who were not accustomed to RT. Leg muscle strength was significantly improved after only four weeks of training, with a linear increase over 16 weeks. Bearing in mind that our study sample consisted predominantly of older women (W:M 68% vs 32%), our results add to the existing literature by demonstrating that older women also experience significant linear gains in leg strength over the course of a RT programme. In addition, we showed that upper body strength improves significantly in older individuals after only four weeks of RT training. With regards to our first research question (Article 1), we have demonstrated that muscle strength increases follow a linear pattern over the course of a RT programme. Additional studies are needed to corroborate our findings and establish what the potential for additional gains is before they reach a plateau in leg muscle strength.

Regarding the second research question (Article 1), it was found that older individuals retained a significant amount of muscle strength after a period of inactivity, which is in accordance with previous research (18, 20). Thus, older individuals can expect rapid increases in muscle strength over the course of a RT programme, while cessation of the programme will result in a decline in strength. However, the magnitude of the strength losses is not proportional to the observed gains obtained over a similar period of training.

2. Submaximal endurance capacity

Submaximal endurance capacity and functional mobility were included as the physical function measures in all three articles. The use of a submaximal test as an indication of aerobic fitness could be considered a limiting factor in the present investigation. However, we chose to use the Bruce treadmill test due to the characteristics of our study sample (i.e. older, inactive individuals). Additionally, this study population generally perform their activities of daily living at a submaximal pace, denoting more ecological validity to the test protocol and the findings.

Although the literature supports the beneficial role of RT for improvements in walking endurance (1, 33), there is still an underlying belief that moderate continuous aerobic training is superior to RT for improvements in aerobic fitness (13, 38). In support of our hypothesis for the second article, it was demonstrated that HIIT produced the biggest gains in walking endurance. RT showed a higher trend towards significance compared to MCT for improvements in aerobic fitness. Even though there was a trend, as we call it, it was still not statistically significant. Therefore, essentially RT did not do better than MCT.

3. Functional mobility

The retention of adequate levels of functional mobility is essential for the maintenance of an independent lifestyle. Due to reports of a reduction in functional mobility with age, research studies have investigated the role of exercise in countering these age-related declines. Interestingly, functional mobility is more readily investigated in RT compared to aerobic training studies (5, 11, 39). Consistent with previous findings, we demonstrated that functional mobility is enhanced with aerobic and resistance exercise training. However, these beneficial effects were of a small magnitude and only evident after 16 weeks. With regards to the ES-values no practically significant improvements were seen.

The findings from the first study allow us to conclude that, in contrast to our hypothesis, increases in muscle strength and physical function were induced in a differential manner over the course of a RT intervention. With regards to the second research question, functional mobility was completely reversed after a period of detraining (DET).

We propose differences in the baseline levels of functionality as a possible explanation for our findings. Due to the high level of functional mobility exhibited by our study sample at pre-test, it could be argued that there was less room for improvement on the Timed-Up-and-Go test. In contrast, the participants presented low levels of muscle strength before the start of the intervention. Thus, the TUG may not be sensitive enough to detect small improvements in an already high functioning population. Future studies should consider adding the level of functional mobility as an inclusion criterion or using a more challenging test in individuals with higher baseline functionality.

B Cognitive function

1. Exercise and the executive function construct

Researchers have come to the understanding that aerobic and resistance exercise training induces the greatest beneficial effects on executive cognitive function, compared to lower levels cognitive processes. This is arguably due to the fact that decreases in the latter are less profound with age (4, 24, 26, 28, 38). Therefore, in the second article we investigated whether HIIT, in addition to RT and MCT, has a selective effect on cognitive function.

Smiley-Oyen *et al.* (38) put forward that the "selective improvement" hypothesis (Article 2) only seems to apply to speeded rather than non-speeded cognitive tasks; mitigating the inclusion of the Stroop task in the present investigation.

The findings reported in this study provide partial support for this “selective improvement” hypothesis. The magnitude of change in reaction time on the Incongruent Stroop condition, a measure of executive function, was statistically significantly greater in the RT group compared to the CON group beyond four weeks. The HIIT and MCT groups showed the same trend as the RT group. No statistically significant differences were observed for all training groups and CON for the information processing (lower level) subtask beyond four weeks (Chapter 3). The HIIT group demonstrated the greatest increase of the ES-value on the executive cognitive tasks beyond the 4-week measurement period, however, this improvement was not statistically significant and thus our hypothesis for the second article could not be fully confirmed. On the other hand, since the CON group showed a statistically significant difference compared to all the training groups in the post-test values of cerebral oxygenation and since the ES-values for the HIIT group was the highest of all the groups, the hypothesis in that sense was confirmed.

Traditional aerobic training has long been deemed the most popular mode of exercise training. This type of exercise is considered safe and easily accessible, especially for the older population. HIIT has been proposed as a viable alternative to traditional endurance training, due to the fact that it is highly effective and time-efficient (19), safe (37) and suitable for older adults limited by disease (42).

As stated by Kemi & Wisløff (23), both healthy subjects and patients with heart disease find interval training more motivating than continuous running at lower intensities, mainly because participants notice rapid effects (such as an improvement in exercise capacity) and because of the reduction in the total exercise time.

The findings reported in the second article provide confirmation that HIIT is a safe and effective training method for health promotion in the older population. Study participants reported no adverse events related to the exercise training. The HIIT group presented the greatest improvement in submaximal endurance capacity, whereas in functional mobility and in executive cognitive function the improvements for the HIIT group were only seen as trends, without a statistically significant difference. We can therefore not fully accept the supposition mentioned in the second article and confirm that there is a relationship between gains in aerobic fitness and improved cognition.

2. Association between physical function and cognitive function

Controversy exists regarding the association between cardiorespiratory fitness and cognitive function. Studies report inconsistent findings and consensus has not been reached on this topic. It has been proposed that cardiorespiratory fitness is not a prerequisite for improved performance on the Stroop task. This assumption appears especially true for the subtask assessing executive function. Despite the fact that Predovan *et al.* (35) found a correlation between fitness and cognitive performance, this relationship was limited to a condition of the Stroop task involving a switching domain. There was no relationship between increased fitness and performance on the Incongruent Stroop condition, confirming a finding formerly reported by Smiley-Oyen *et al.* (38). It has been stated that there is a correlation between absolute aerobic fitness levels and cognitive performance, whereas changes in fitness over the course of an intervention programme do not relate to the observed changes in behavioural performance (38). This statement can be confirmed, to some extent, by the results reported in the third chapter. Compared to the CON group, all the training groups showed an improvement in executive cognitive function. On the other hand, the MCT group did not show an increase in their aerobic fitness level after the intervention period. Then again, Hotting *et al.* (22) demonstrated that improvements in episodic memory are associated with increases in cardiovascular fitness. Therefore, the former statement by Smiley-Oyen *et al.* (38) could arguably only hold true for executive cognitive function.

3. Mechanisms for the enhancement of cognitive function

Researchers have investigated the possible mechanisms underlying the enhancement of cognitive processes. Changes in brain volume (10, 15), cerebral blood flow (2, 6, 8) and the availability and signalling cascades of growth factors (16) are believed to be factors mediating the positive relationship between exercise and cognition. Angiogenesis (the formation of new blood vessels from existing vessels) accompanies the exercise-induced stimulation of neurogenesis (formation of new neurons), due to the increased metabolic demands of the brain (12). The beneficial effects can furthermore be attributed to exercise-induced hypertrophy of the hippocampus, which provide protection against neural degeneration (15).

There are a number of mechanisms whereby aerobic exercise may improve cognitive function. Cardiovascular exercise training improves cerebral blood flow (8) and functional and structural connectivity between neural networks (synaptogenesis), while also reducing inflammation and serving a protective effect against the decline in brain volume associated with aging (10, 30).

Liu-Ambrose & Donaldson (27) proposed that increased levels of insulin-like growth factor I (IGF-I) and decreased levels of serum homocysteine are possible mechanisms whereby RT may prevent cognitive decline among elderly individuals. These mechanisms play a vital role in the preservation of brain and cognitive health with senescence.

4. Exercise training and cerebral oxygenation

Near-infrared spectroscopy (NIRS) has been successfully used in research studies to measure cerebral oxygenation. The primary application of NIRS to the human body uses the fact that the transmission and absorption of NIR light in human body tissues contains information about haemoglobin concentration changes. When a specific area of the brain is activated, the localized blood volume in that area changes quickly. As shown by NIRS investigations, enhanced cerebral activation is the result of an increase in the concentration of oxy-haemoglobin and a decrease in the deoxy-haemoglobin concentration (40).

It was established that performance on the Stroop task shows a strong association with activation on the left prefrontal cortex (3), which supports our decision to focus on this area of the brain for activation/oxygenation changes. The increased brain oxygenation response during cognitive stimulation can be attributed to enhanced neuronal activation. This pattern is the result of an increase in the concentration of oxy-haemoglobin and total haemoglobin and a decrease in the concentration of deoxy-haemoglobin (41). Neurovascular coupling leads to increases in regional cerebral blood flow to support the enhanced neuronal activity (12).

The use of NIRS and the investigation into the effects of three exercise training modalities on prefrontal brain oxygenation have not been previously documented and, until now, the effects of HIIT were unknown. The findings reported in the third article adds to the current literature by demonstrating that cerebral oxygenation during cortical activation is training mode dependent. Not only HIIT, as hypothesized, but also MCT was shown to result in more efficient brain activation patterns compared to RT and no exercise. In addition, RT proved to induce more task-efficient activation compared to CON. We provide new insights regarding the link between brain activation patterns and cognitive performance, since the CON participants required increased neuronal activation in order to perform at a comparable behavioural level than the training groups (Article 3). We propose that our aerobic exercise training groups experienced structural brain changes together with functional changes in neural networks essential for cognitive processing, enabling them to perform at a more efficient level (14).

These findings add to the brain and cognition research and have a number of practical implications. If exercise training results in more efficient brain activation patterns in healthy, older individuals, the possibility exists that diseased populations will also experience these health-related benefits. Future studies should build upon our research findings and investigate whether aerobic exercise training result in more efficient brain oxygenation responses in diseased populations and/or aid in the prevention of pathological mechanisms associated with cognitive impairment. This will present researchers with valuable insights into the therapeutic benefits of exercise.

C Study strengths and limitations

1. Near-infrared spectroscopy (NIRS)

NIRS is a cost-effective method that is portable and relatively easy to administer. This method is sensitive for the detection of changes in cerebral oxygenation during cortical activation. Another advantage of NIRS is that it can be used for repetitive examinations (36).

Even though we observed changes in activation patterns in the prefrontal cortex, this study was not designed to show possible activation changes in other brain regions. A direction for future research would be to use a multi-channel NIR spectrometer in order to determine if different exercise training modalities induce activation changes in brain regions other than the prefrontal cortex.

2. The Stroop task as a measure of executive function

The Stroop task is a popular test used in exercise intervention studies assessing cognitive performance. However, differences in the test design (verbal response vs. computerized response) lead to the inability to accurately compare the results across studies. The inconsistency in operationally defining which aspects of cognitive function are measured by which Stroop task adds an additional problem to the interpretation of results and comparing the effects of different modes of exercise on cognition.

The Stroop task presents several strengths and weaknesses. This test is cost-effective, not very time consuming and easy to administer. In addition, the computerized version is designed to give a randomized sequence of trials at each testing session. Nevertheless, as with any test of cognitive function, the possibility of a learning effect exists. Earlier research has indicated that the Incongruent Stroop task possesses adequate test-retest reliability in healthy young individuals over a short period, i.e. two weeks (17), whereas the same inter-assessment interval has been shown to induce a practice effect in middle-aged to elderly subjects (25).

Pachana *et al.* (32) also reported a practice effect on the executive function condition of their modified Stroop task after the preliminary month of testing in healthy and Type-II diabetics. The participants did not take part in any specific training intervention. High correlations were found between reaction times on their California Older Adult Stroop Test and the traditional Stroop task, making the tests comparable. The results from the second to the third month of testing revealed that Stroop reaction time had reached a plateau, which is parallel to our CON group's behavioural performance (Article 2). In addition, Pachana *et al.* (32) reported no evidence of a practice effect on any of the Stroop conditions in the dementia patients.

We would thus advise careful consideration for the use of the Stroop task in longitudinal studies employing repeated measures. We had to exclude 11 participants (six in the HIIT group and five in the MCT group) who previously formed part of either the RT or CON groups, because we did not foresee that a learning effect will persist after a year of testing. This carry-over effect a year after the initial testing is a new finding that renders its use in an experimental setting problematic. It is however worth mentioning that these participants could have continued exercising after their participation in the first intervention (evident from the significant increases in walking endurance after DET compared to baseline in Article 1). Thus, the possibility that these individuals presented with better cognitive function a year later may in fact reflect the effect of regular exercise training, rather than merely a learning effect.

The cognitive results in the second article are limited to, and could have been influenced by the reduced sample sizes of the HIIT and MCT groups. For this reason magnitude-based differences (effect sizes) were included in the analysis, as this statistic is not affected by sample size and is also a better reflection of the practical implications of the findings, than traditional hypothesis testing.

Our study population consisted of healthy individuals, with above average levels of education and functional mobility. It could be argued that they had the ability to adjust easily and become accustomed to the demands of the Stroop task. Therefore, the lack of statistically significant between-group differences in the change in Stroop performance could also be attributed to the fact that our study participants had a relatively high level of functioning before the start of the intervention. Thus, this task might best be used with participants exhibiting lower levels of education and/or cognitive function, who are less likely to become familiarized with the task-design (32).

Since the research field of exercise and cognition is expanding rapidly, future investigations should determine which test of cognitive function would be most suitable for different populations.

3. Training programmes

The HIIT and MCT programmes were designed to be isocaloric and thus adds strength to the present study. A limiting factor, however, is that it could not be quantified whether the RT programme was isocaloric to the two aerobic training programmes. We can therefore not exclude these dissimilarities as a possible explanation for the differences observed in the functional outcomes.

The design of the RT programme could be considered one of the strengths of the study. The progression in the intensity seemed ideal for our study sample, as we included older people who were not accustomed to RT. We therefore decided to use a programme where the intensity progressively increased over the three sets for each exercise. The results show that this programme was very well structured for the participants and highlights RT as a safe and effective method for the enhancement of muscular and physical function in an older population. None of the study participants reported any adverse events during the course of the training intervention and we had a 100% study completion rate.

This investigation was not only done to compare the three exercise training modalities, but also with the idea to show that all three training modes are beneficial for the older individuals. Our recommendation for the older population would be to try and incorporate aspects of each exercise modality into their training regime.

4. Gender differences

It is uncertain if gender differences had an influence on the results of the present study. Even though there were more women than men in each training group, the men were equally distributed across groups, eliminating the possibility of gender biases influencing the results. In their meta-analysis Colcombe & Kramer (9) arrived at the conclusion that study samples consisting of more than 50% women yielded higher average effect sizes for the exercise effects on cognition, compared to samples consisting predominantly of males (0.604 vs 0.150). Therefore, the influence of gender is a prospective avenue for future investigations, especially with regards to cerebral oxygenation levels.

5. Factors affecting cognitive function

There are a number of external and individual factors that could have an effect on one's cognitive function, including motivation, social participation (7) and sunlight exposure (31). Our study sample did not comprise of socially isolated older adults; therefore the added social contact due to participation in the study would not have had a profound effect. Additionally, the changes in the climate in South Africa from one season to the next are not of such an extreme nature compared to European countries. Therefore it is unlikely that dramatic changes in sunlight exposure occurred which could have affected the results.

D Conclusion

The findings of this thesis demonstrated that the enhancement of physical and cognitive function in a healthy older population is dependent on the exercise training mode. HIIT was superior to RT and MCT for gains in submaximal endurance capacity, whereas only RT showed a statistically significant improvement in executive cognitive function, with HIIT and MCT exhibiting a similar trend. In addition, both resistance and aerobic training are beneficial for cerebral oxygenation during cortical activation, compared to no exercise. It was found that the latter is training mode dependent, with aerobic exercise proving more effective than RT.

Take home message

Older adults can benefit from both aerobic and resistance exercise training for gains in physical and cognitive function. Therefore, this population should incorporate a combination of these training modalities in their weekly exercise routines for the promotion of health and wellbeing.

REFERENCES

1. Ades PA, Ballor DL, Ashikaga T, Utton JL, Nair KS. Weight training improves walking endurance in healthy elderly persons. *Ann Intern Med*. 1996;124(6):568–72.
2. Ainslie PN, Cotter JD, George KP, *et al.* Elevation in cerebral blood flow velocity with aerobic fitness throughout healthy human ageing. *J Physiol*. 2008;586(16):4005–10.
3. Alvarez JA, Emory E. Executive function and the frontal lobes: a meta-analytic review. *Neuropsychol Rev*. 2006;16(1):17–42.
4. Anderson-Hanley C, Nimon JP, Westen SC. Cognitive health benefits of strengthening exercise for community-dwelling older adults. *J Clin Exp Neuropsychol*. 2010:32(9):996–1001.
5. Arnarson A, Geirsdottir OG, Ramel A, Briem K, Jonsson PV, Thorsdottir I. Effects of whey proteins and carbohydrates on the efficacy of resistance training in elderly people: double blind, randomised controlled trial. *Eur J Clin Nutr*. 2013;67(8):821–6.
6. Bailey DM, Marley CJ, Brugniaux JV, *et al.* Elevated aerobic fitness sustained throughout the adult lifespan is associated with improved cerebral hemodynamics. *Stroke*. 2013;44(11):3235–8.
7. Bourassa KJ, Memel M, Woolverton C, Sbarra DA. Social participation predicts cognitive functioning in aging adults over time: comparisons with physical health, depression, and physical activity. *Aging Ment Health.* 2015:1-14.
8. Brown AD, McMorris CA, Longman RS, *et al.* Effects of cardiorespiratory fitness and cerebral blood flow on cognitive outcomes in older women. *Neurobiol Aging*. 2010;31(12):2047–57.
9. Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci*. 2003;14(2):125–30.
10. Colcombe SJ, Erickson KI, Scalf PE, *et al.* Aerobic exercise training increases brain volume in aging humans. *J Gerontol A Biol Sci Med Sci*. 2006;61(11):1166–70.
11. Correa CS, Cunha G, Marques N, Oliveira-Reischak Ã, Pinto R. Effects of strength training, detraining and retraining in muscle strength, hypertrophy and functional tasks in older female adults. *Clin Physiol and Funct Imaging*. 2015:1–5.
12. Davenport MH, Hogan DB, Eskes GA, Longman RS, Poulin MJ. Cerebrovascular reserve: the link between fitness and cognitive function? *Exerc Sport Sci Rev*. 2012;40(3):153–8.

13. Dustman RE, Ruhling RO, Russell EM, *et al.* (1984). Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiol Aging*. 1984;5(1):35–42.
14. Erickson KI, Kramer AF. Aerobic exercise effects on cognitive and neural plasticity in older adults. *Br J Sports Med*. 2009;43(1):22–4.
15. Erickson KI, Voss MW, Prakash RS, *et al.* Exercise training increases size of hippocampus and improves memory. *Proc Natl Acad Sci USA*. 2011;108(7):3017–22.
16. Foster PP, Rosenblatt KP, Kuljiš RO. Exercise-induced cognitive plasticity, implications for mild cognitive impairment and Alzheimer's disease. *Front Neurol*. 2011;2(28):1–15.
17. Franzen MD, Tishelman AC, Sharp BH, Friedman AG. An investigation of the test-retest reliability of the Stroop Color-Word Test across two intervals. *Arch Clin Neuropsychol* 1987;2(3):265–72.
18. Geirsdottir OG, Arnarson A, Ramel A, Briem K, Jonsson PV, Thorsdottir I. Muscular strength and physical function in elderly adults 6-18 months after a 12-week resistance exercise program. *Scand J Public Health*. 2015;43(1):76–82.
19. Gibala MJ, Little JP, MacDonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol*. 2012;590(5):1077–84.
20. Harris C, DeBeliso M, Adams KJ, Irmischer BS, Spitzer Gibson TA. Detraining in the older adult: effects of prior training intensity on strength retention. *J Strength Cond Res*. 2007;21(3):813–8.
21. Henwood T, Tuckett A, Edelstein O, Bartlett H. Exercise in later life: the older adults' perspective about resistance training. *Ageing Soc*. 2011;31(8):1330–49.
22. Hötting K, Röder B. Beneficial effects of physical exercise on neuroplasticity and cognition. *Neurosci Biobehav Rev*. 2013;37(9):2243–57.
23. Kemi OJ, Wisløff U. High-intensity aerobic exercise training improves the heart in health and disease. *J Cardiopulm Rehabil Prev*. 2010;30(1):2–11.
24. Kramer AF, Hahn S, Cohen NJ, *et al.* Ageing, fitness and neurocognitive function. *Nature*. 1999;400(6743):418–9.
25. Lemay S, Bédard M-A, Rouleau I, Tremblay P-L. Practice effect and test-retest reliability of attentional and executive tests in middle-aged to elderly subjects. *Clin Neuropsychol*. 2004;18(2):284–302.

26. Liu-Ambrose T, Donaldson MG, Ahamed Y, *et al.* Otago home-based strength and balance retraining improves executive functioning in older fallers: a randomized controlled trial. *J Am Geriatr Soc*. 2008;56(10):1821–30.
27. Liu-Ambrose T, Donaldson MG. Exercise and cognition in older adults: is there a role for resistance training programmes? *Br J Sports Med*. 2009;43(1):25–7.
28. Liu-Ambrose T, Nagamatsu LS, Graf P, Beattie BL, Ashe MC, Handy, TC. Resistance training and executive functions: a 12-month randomized controlled trial. *Arch Intern Med*. 2010;170(2):170–8.
29. Lovell D, Cuneo R, Delphinus E, Gass G. Leg strength and the $\dot{V}O_{2max}$ of older men. *Int J Sports Med*. 2011;32(4):271–6.
30. McAuley E, Mullen SP, Hillman CH. Physical activity, cardiorespiratory fitness, and cognition across the lifespan. In: *Social Neuroscience and Public Health*. Springer; 2013 p. 235–52.
31. Miller JW, Harvey DJ, Beckett LA, *et al.* Vitamin D status and rates of cognitive decline in a multiethnic cohort of older adults. *JAMA Neurol.* 2015:E1-9.
32. Pachana NA, Thompson LW, Marcopulos BA, Yoash-Gantz R. California Older Adult Stroop test (COAST) development of a Stroop test adapted for geriatric populations. *Clin Gerontol*. 2004;27(3):3–22.
33. Parker ND, Hunter GR, Treuth MS, *et al.* Effects of strength training on cardiovascular responses during a submaximal walk and a weight-loaded walking test in older females. *J Cardiopulm Rehabil Prev*. 1996;16(1):56–62.
34. Pinto RS, Correa CS, Radaelli R, Cadore EL, Brown LE, Bottaro M. Short-term strength training improves muscle quality and functional capacity of elderly women. *AGE*. 2014;36(1):365–72.
35. Predovan D, Fraser SA, Renaud M, Bherer L. The effect of three months of aerobic training on Stroop performance in older adults. *J Aging Res*. 2012;2012:1–7.
36. Schroeter ML, Zysset S, Kupka T, Kruggel F, Von Cramon DY. Near-infrared spectroscopy can detect brain activity during a Color-Word matching Stroop task in an event-related design. *Hum Brain Mapp*. 2002;17(1):61–71.
37. Shiraev T, Barclay G, others. Evidence based exercise: Clinical benefits of high intensity interval training. *Aust Fam Physician*. 2012;41(12):960–2.
38. Smiley-Oyen AL, Lowry KA, Francois SJ, Kohut ML, Ekkekakis P. Exercise, fitness, and neurocognitive function in older adults: the “selective improvement” and “cardiovascular fitness” hypothesis. *Ann Behav Med*. 2008;36(3):280–91.

39. Sousa N, Sampaio J. Effects of progressive strength training on the performance of the functional reach test and the timed get-up-and-go test in an elderly population from the rural north of Portugal. *Am J Hum Biol.* 2005;17(6):746–51.
40. Strangman G, Franceschini MA, Boas DA. Factors affecting the accuracy of near-infrared spectroscopy concentration calculations for focal changes in oxygenation parameters. *Neuroimage*. 2003;18(4):865–79.
41. Villringer A, Planck J, Hock C, Schleinkofer L, Dirnagl U. Near infrared spectroscopy (NIRS): a new tool to study hemodynamic changes during activation of brain function in human adults. *Neurosci Lett*. 1993;154(1):101–4.
42. Whitehurst M. High-intensity interval training an alternative for older adults. *Am J Lifestyle Med*. 2012;6(5):382–6.

Appendix A

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Approval Notice
New Application

09-Apr-2013
Terblanche, Elmarie E

Protocol #: HS891/2013
Title: The dose-response relationship of resistance exercise on health and functional related outcomes in older individuals.

Dear Professor Elmarie Terblanche,
The **New Application** received on **25-Jan-2013**, was reviewed by members of **Research Ethics Committee: Human Research (Humanities)** via Expedited review procedures on **09-Apr-2013** and was approved.
Please note the following information about your approved research protocol:

Protocol Approval Period: **09-Apr-2013 -08-Apr-2014**

Standard provisions

1. The researcher will remain within the procedures and protocols indicated in the proposal, particularly in terms of any undertakings made in terms of the confidentiality of the information gathered.
2. The research will again be submitted for ethical clearance if there is any substantial departure from the existing proposal.
3. The researcher will remain within the parameters of any applicable national legislation, institutional guidelines and scientific standards relevant to the specific field of research.
4. The researcher will consider and implement the foregoing suggestions to lower the ethical risk associated with the research.

You may commence with your research with strict adherence to the abovementioned provisions and stipulations.
Please remember to use your **protocol number** (**HS891/2013**) on any documents or correspondence with the REC concerning your research protocol.
Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:

Please note that a progress report should be submitted to the Committee before the approval period has expired if a continuation is required.
The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.
National Health Research Ethics Committee (NHREC) number REC-050411-032.
This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant parties. For approvals from the Western Cape Education Department, contact Dr AT Wyngaard (awyngaar@pgwc.gov.za, Tel: 0214769272, Fax: 0865902282, http://wced.wcape.gov.za). Institutional permission from academic institutions for students, staff & alumni. This institutional permission should be obtained before submitting an application for ethics clearance to the REC.

Please note that informed consent from participants can only be obtained after ethics approval has been granted. It is your responsibility as researcher to keep signed informed consent forms for inspection for the duration of the research.

We wish you the best as you conduct your research.
If you have any questions or need further help, please contact the REC office at 0218089183.

Included Documents:
Questionnaire
Sincerely,
Susara Oberholzer
REC Coordinator
Research Ethics Committee: Human Research (Humanities)
Revised Informed Consent Afrikaans
Revised Research proposal
Revised Informed consent English
REC Application
Letter to REC
Consent form Eng
Consent form (afr)
research proposal

Appendix B

HEALTH SCREENING FORM

Voltooi die volgende vrae so akkuraat as moontlik. Maak 'n regmerkie in die toepaslike blokkie (ڤ). Dit is tot u eie voordeel om die vrae so eerlik as moontlik te beantwoord. / *Complete the following questions as accurately as possible. Check the applicable block* (ڤ). *It is to your own benefit to complete the questions as honest as possible.*

1. Laaste mediese ondersoek / *Last medical exam:* ______________________________(Jaar / *Year*)

   Laaste fiksheidstoets / *Last fitness test:* _____________________________________ (Jaar / *Year*)

2. Het u 'n geskiedenis van enige van die volgende / *Do you have a history of any of the following?*

   ڤ Hartaanval / *Heart attack*
   ڤ Koronêre trombose / *Coronary thrombosis*
   ڤ Vernoude are / *Narrowing arteries*
   ڤ Hoë cholesterol / *High cholesterol*
   ڤ Hoë bloeddruk / *High blood pressure*
   ڤ Rumatiek koors / *Rheumatic fever*
   ڤ Beroerte aanval / *Stroke*
   ڤ Angina (Borspyne) / *Chest pains*
   ڤ Lekkende hartklep / *Leaking heart valve*
   ڤ Diabetes / *Diabetes*
   ڤ Artritis / *Arthritis*
   ڤ Epilepsie / *Epilepsy*
   ڤ Kardiovaskulêre siekte / *Cardiovascular diseas*
   ڤ Palpitasies / *Palpitations*
   ڤ Pulmonale siekte / *Pulmonary disease*
   ڤ Geswelde enkels / *Ankle edema*
   ڤ Metaboliese siekte / *Metabolic disease*
   ڤ Dispnee (asemnood) / *Dyspnea*
   ڤ Hartgeruis / *Heart murmur*
   ڤ Intermittende klaudikasie / *Intermittent claudication*

3. Het u 'n familiegeskiedenis van een van die volgende / *Do you have a family history of any of the following?*

   ڤ Hartaanval / *Heart attack*
   ڤ Koronêre hartsiekte < 60jr / *Coronary heart disease < 60yrs*
   ڤ Hoë cholesterol / *High cholesterol*
   ڤ Hoë bloeddruk / *High blood pressure*
   ڤ Beroerte aanval / *Stroke*
   ڤ Oorgewig / *Overweight*
   ڤ Suikersiekte / *Diabetes*

4. Het u enige allergieë / *Do you have any allergies?* ڤ Ja / *Yes* ڤ Nee / *No*

   Indien ja, noem dit / *If yes, name it:*____

5. Merk een van die volgende. Gedurende 'n normale dag is ek: / *Check one of the following. During a normal day I am:*

   ڤ Nooit gespanne / *Never tense* ڤ Weinig gespanne / *Seldom tense* ڤ Van tyd tot tyd gespanne / *Tense from time to time* ڤ Gereeld gespanne of angstig / *Often tense or anxious*

   ڤ Gewoonlik gespanne of angstig / *Normally tense or anxious*

6. Hoe gereeld neem u aan fisieke aktiwiteite of oefening deel / *How often do you participate in physical activity or exercise?*

   Keer per week / *Times per week:*_______ Duur / *Duration:*_________ Tipe / *Type:*____________________

____

7. Voel u ooit / *Do you ever experience:*

Kort van asem tydens rus of met ligte oefening? / *Shortness of breath at rest or with mild exertion?*_________

Moeg of kort van asem met daaglikse aktiwiteite? / *Unusual fatigue or shortness of breath with daily activities?*

____

8. Beskryf asseblief u rook geskiedenis / *Please describe you history of smoking:* __________________________

9. Het u 'n geskiedenis van enige gewrigs- of spierbeserings / *Do you have a history of any joint or muscle injury?*

ڤ Nek / *Neck* ڤ Bo-rug / *Upper back* ڤ Lae rug / *Lower back* ڤ Heup / *Hip*

ڤ Bobeen / *Thigh* ڤ Knie / *Knee* ڤ Onder-been / *Lower leg* ڤ Enkel / *Ankle*

ڤ Voet / *Foot* ڤ Skouer / *Shoulder* ڤ Elmboog / *Elbow* ڤ Pols of gewrig / *Wrist or hand*

10. Gebruik u gereelde medikasie / *Are you on regular medication?* ڤ Ja / *Yes* ڤ Nee / *No*

Indien ja, wat is die naam, dosis en die gebruik daarvan / *If yes, what is the name, dosage and use thereof?* :__

Kondisie: bv. Cholesterol	*Medikasie: bv. Lipitor*	*Dosis: bv. 10mg / dag*
____________________	__________________	__________________
____________________	__________________	__________________
____________________	__________________	__________________
____________________	__________________	__________________

11. Het u dokter voorheen aangedui dat u enige ander kondisie het waarvan ons moet kennis neem / *Have your doctor previously indicated any other conditions that we should be aware of?* _________________________________

____

____

PAR-Q & YOU

Common sense is your best guide when you answer the following questions. Please read the questions carefully and answer each one.

ڤ Yes ڤ No Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

ڤ Yes ڤ No Do you feel pain in your chest when you do physical activity?

ڤ Yes ڤ No In the past month, have you had chest pain when you were not doing physical activity?

ڤ Yes ڤ No Do you lose your balance because of dizziness or do you ever lose consciousness?

ڤ Yes ڤ No Do you have a bone or joint problem that could be made worse by a change in your physical activity?

ڤ Yes ڤ No Is your doctor currently prescribing drugs (for example water pills for blood pressure or heart conditions)?

ڤ Yes ڤ No Do you know of any other reason why you should not do physical activity?

Hiermee verklaar ek dat ek die prosedure van evaluasie verstaan en dat ek die geleentheid gehad het om al die relevante vrae betreffende die evaluasie met die Biokinetikus te bespreek. Ek neem op eie risiko deel aan die evaluasie. *I hereby declare that I fully understand the procedure of the evaluation and that I had the opportunity to discuss any questions relevant to the evaluation with the Biokineticist. I participate in this evaluation at my own risk.*

Pasiënt Handtekening / *Patient Signature*

Datum / *Date*

Biokinetikus / *Biokineticist*

Datum / *Date*

Appendix C

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

THE RELATION OF EXERCISE TRAINING MODE, BRAIN OXYGENATION AND COGNITION IN HEALTHY OLDER ADULTS

You are asked to participate in a research study conducted by Prof E Terblanche (PhD) and Dr P Olivier (PhD) from the Department of Sport Science at Stellenbosch University. Aspects of this research project will form part of the theses of one Masters in Sport Science student (Ms S Nieuwoudt (15617572) and one PhD in Sport Science student (Carla Coetsee, 15365484) in the Department of Sport Science. You were selected as a possible participant in this study because you are between the ages of 55 and 75 years.

1. PURPOSE OF THE STUDY

The purpose of this study is to obtain an understanding of the effects of three exercise training modes (resistance training, high-intensity interval training and moderate continuous training) on physical function and cognitive health in older individuals. The question is therefore asked which mode of exercise will be most beneficial for this population.

2. PROCEDURES

If you volunteer to participate in the study, we will ask you to do the following during visits to the Sport Physiology Laboratory:

1. measures of resting blood pressure, heart rate, glucose, height and weight, static and dynamic balance;
2. donate a blood sample of 10 mL (taken by a qualified nurse) to determine your cholesterol values;
3. complete questionnaires on your health, activity level and mental well being;
4. a resting ECG test;
5. muscle strength tests of your upper and lower body;
6. the “Timed-Up-and-Go” (TUG) test to determine how quickly you can get up from a chair, walk three meters, turn, walk back and sit on the chair;
7. a walk test on a treadmill during which the speed and slope will increase progressively while your oxygen consumption is measured until you cannot maintain the speed;
8. a test on the computer to determine how quickly you respond to a visual stimulus;
9. complete measures of brain blood flow through stickers on your forehead.

The tests above will be completed over two days. Hereafter you will be randomly allocated to a specific exercise group. We will request you to visit the Biokinetics Centre either once per week or three time per week for an exercise session. The exercise program will last 16 weeks. The sessions will be 30 to 60 minutes each and will consist of moderate to high intensity walking on the treadmill. Every four weeks some of the tests, as indicated above, will be repeated (i.e. balance, functional capacity, muscle strength, brain blood flow and the computer test). On completion of the 16 week exercise program, all the tests above will be repeated.

3. POTENTIAL RISKS AND DISCOMFORTS

There are no serious risks involved in the tests or the exercise program. You may experience dizziness and nausea during the test and exercise sessions on the treadmill. If so, the exercise will be stopped immediately. You may also experience temporary discomfort, like muscle soreness or stiffness, after the first few exercise sessions.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

The results of all the measurements and tests will be given to you, which will lead to personal enrichment. You can also look forward to improved fitness levels and functional capacity over the course of the 16-week programme.

5. PAYMENT FOR PARTICIPATION

You will receive no compensation for your participation in this study. However, if you're in the exercise groups you will receive exercise sessions free of charge for the duration of the intervention period (16 weeks).

Should you incur any research-related injury or incident, all costs will be covered by the Department of Science.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of giving participants numbers to identify them so no one will be identified using their names. The data collected will be stored in a computer which is password protected and only the researchers and the postgraduate students will have access to it. This computer will be locked in an office.

You will receive a report on your results on completion of the intervention. The findings of the study (i.e. group results) will be published in scientific journals and confidentiality will be maintained in that your (or any other participant's) name will not be mentioned. Selected results will form part of the research theses of the two postgraduate students. The department will keep the data for a period of 5 years and then it will be destroyed.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. This may happen if you fall ill, get injured or if there are any adverse effects during or after the exercise tests or exercise sessions.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact any of the following persons:

Prof E. Terblanche (Principle investigator) by 021 808 4817. E-mail: et2@sun.ac.za.
Dr P Olivier (Co-investigator) by 021 808 4718. E-mail: polivier@sun.ac.za
Me Carla Coetsee (PhD-student) by 021 808 2818. E-mail: 15365484@sun.ac.za
Me Sharné Nieuwoudt (MSc-student) by 021 808 2818. E-mail: 15617572@sun.ac.za

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to me ______________________________ (name) by ________________________ (researcher) in _________________ (language) and I am in command of this language or it was satisfactorily translated to me. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

____

Name of Subject/Participant

____

Name of Legal Representative (if applicable)

____ _______________

Signature of Subject/Participant or Legal Representative **Date**

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to ___________________ [*name of the subject/participant]* and/or [*his/her*] representative _____________________ [*name of the representative]. [He/she*] was encouraged and given ample time to ask me any questions. This conversation was conducted in [*Afrikaans/*English/*Xhosa/*Other*] and no translator was used.

____ _______________

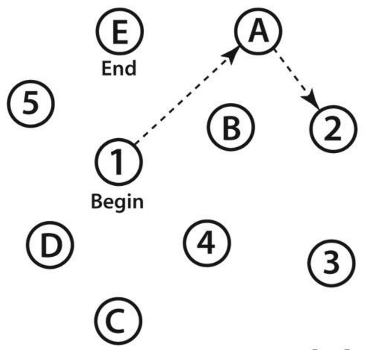
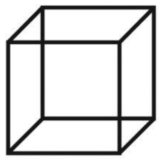
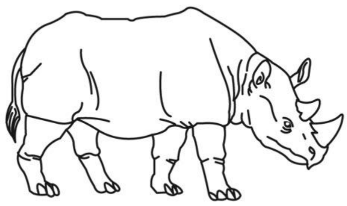
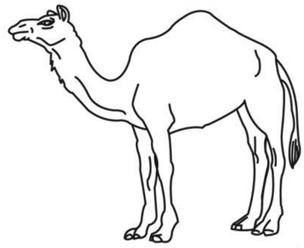
Signature of Investigator **Date**

Appendix D

MONTREAL COGNITIVE ASSESSMENT

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education :
Sex :
Date of birth :
DATE :

		POINTS
VISUOSPATIAL / EXECUTIVE  [ ]	 Copy cube [ ]	
Draw CLOCK (Ten past eleven) (3 points)	[ ] Contour [ ] Numbers [ ] Hands	___/5
NAMING  [ ]  [ ]  [ ]		___/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2 ___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B ___/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt** ___/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ] ___/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words) ___/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler ___/2

DELAYED RECALL	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only	___/5
Optional	Category cue							
	Multiple choice cue							

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City ___/6

© Z.Nasreddine MD **www.mocatest.org** Normal ≥ 26 / 30

TOTAL ___/30
Add 1 point if ≤ 12 yr edu

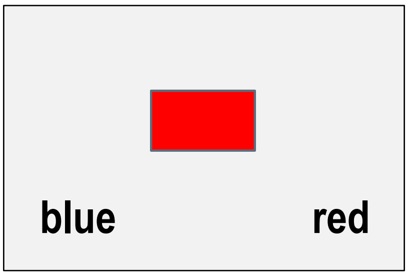
Administered by: ______________________________

Appendix E

STROOP TASK CONDITIONS

Neutral condition

Select the word that describes the colour of the BLOCK



Incongruent condition

Select the word that describes the text COLOUR of the middle word

blue

red **green**